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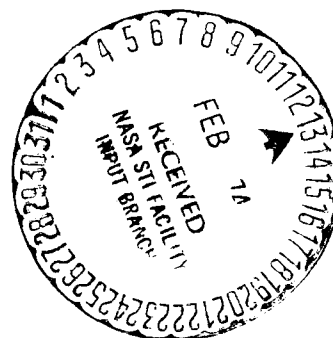
MSC INTERNAL NOTE NO. 69-FM-304

November 10, 1969

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FINAL OPERATIONAL
SPACECRAFT ATTITUDE
SEQUENCE FOR
APOLLO 12 (MISSION H-1)



Lunar Mission Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

(NASA-TM-X-69809) FINAL OPERATIONAL
SPACECRAFT ATTITUDE SEQUENCE FOR APOLLO
12 (MISSION H-1) (NASA) 129 p

N74-70727

Unclas

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16441

Internal Note No. 69-FM-304

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PROJECT APOLLO
FINAL OPERATIONAL SPACECRAFT ATTITUDE
SEQUENCE FOR APOLLO 12
(MISSION H-1)

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November 10, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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NOTE

The REFSMMAT's for lunar orbit plane changes and TEI were computed in the Apollo 12 operational trajectory to be preferred for a heads-down burn. This cannot be done in real time in the RTCC; therefore, the REFSMMAT's in this document have been rotated 180° in roll to a heads-up REFSMMAT to simulate more closely the real-time situation. Because this change does not take into account c.g. offsets, the resulting REFSMMAT and pitch and yaw gimbal angles at burn initiation are not exactly correct.

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FINAL OPERATIONAL SPACECRAFT ATTITUDE SEQUENCE

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1. SUMMARY AND INTRODUCTION

1.1 General

This document contains the final operational spacecraft attitude sequence for mission H-1. The purpose of the document is to provide a source of spacecraft (command and service module (CSM) and lunar module (LM)) attitude data for the nominal cislunar and lunar orbit mission operations. Changes and revisions to the operational H-1 mission lunar orbit attitude sequence, Reference 1, have been incorporated in order to present the latest possible mission planning inputs. These updates include several changes to the attitude philosophy. Periods of landmark tracking on site H-1 have changed significantly due to a change in the landmark coordinates from approximately 35 degrees east longitude to 15 degrees west longitude. The abort guidance system (AGS) calibration attitude changed to avoid approaching gimbal lock when using the V49 auto maneuver to the undocking attitude. The LM procedures from descent orbit insertion (DOI) to landing have been updated to delete the landing radar (LR) test prior to powered descent initiation (PDI). A CSM attitude maneuver has been included during the sixteenth revolution, which allows oblique-view tracking of the LM. The plane change 1 burn is now performed two revolutions later and has been changed to a heads-up burn with a corresponding change in the plane change 1 REFSMMAT. The CSM attitude during the in-plane S158 photography periods has been changed to include a vehicle roll angle of 0 degree. This photography attitude eliminates the necessity of a maneuver for S-band high-gain antenna (HGA) communications between the first and second S158 photography periods. Out-of-plane (vehicle yawed)

S158 photography of the landmarks Theophilus, Descartes, and Fra Mauro has been included in the twenty-eighth revolution. The LM ascent profile now includes a 20-degree pilot yaw maneuver after lift-off. This maneuver provides MSFN - S-band steerable HGA communications during the ascent phase. The inertial measurement unit (IMU) realignment attitude for the LM after LM lunar orbit insertion has been changed to duplicate the inertial realignment attitude prior to DOI. A constant delta altitude (CDH) burn maneuver was not required for this simulation.

The LM jettison attitude has been changed to reflect the new LM impact burn attitude. A period of CSM SXT tracking of the LM after jettison has been added. The lunar orbit plane change 2 burn has been changed to a heads-up burn with a corresponding change in the plane change 2 REFSMMAT. This change was made to establish CSM S-band HGA communications for the burn. A period of high resolution photography of Lalande has been added in revolution 39 after the plane change 2 burn. A new CSM REFSMMAT has been added between the plane change 2 REFSMMAT and the TEI REFSMMAT. This in-plane photography REFSMMAT allows the CSM to retain an in-plane REFSMMAT for photography and landmark tracking until just prior to TEI. A different maneuver has been inserted after landmark tracking in revolutions 42 and 43 to establish easier HGA acquisition. A new attitude sequence has been added after the strip photography in revolution 44 to reduce the number of attitude maneuvers. The TEI REFSMMAT has been changed to a heads-up REFSMMAT even though the TEI burn has remained heads down. In addition, the cislunar attitude sequence has been included.

Cislunar and lunar orbit data for the spacecraft operational attitude sequence are presented in the following format:

1. Discussion of the major attitude events occurring in the mission
2. Figures illustrating the spacecraft attitude events and activities. Each figure illustrates the body attitudes with respect to the moon, sun, and earth and indicates CSM local horizontal (LH) roll, LH pitch, inertial pitch, and LH yaw, respectively. Also, where applicable, the figures indicate LM FDAI roll, ORDEAL pitch, FDAI pitch, and FDAI yaw, respectively. Mission event times were obtained from the Apollo 12 Final Flight Plan (Reference 2).
3. Tabular data summarizing the pertinent spacecraft attitude and orbital parameters (Table I). The pertinent spacecraft attitude and orbital data presented include
 - a. Mission time
 - b. Event
 - c. Selenographic position

d. Local horizontal attitude; that is, the local horizontal X-axis lies along the local horizontal in the direction of motion; the Z-axis lies along the negative radius vector; and the Y-axis completes the right hand, orthogonal system.

e. Inertial measurement unit (IMU) gimbal angles are presented for the CSM during CSM/LM docked and CSM solo operations and for both the CSM and LM during two-vehicle operations. Flight director attitude indicator (FDAI) readings are also presented for the LM. The exact conversion from IMU to FDAI inertial angles for the LM can be found in Reference 3. The conversion is necessary because the pilot orientations differ between the CSM and LM even though the guidance and navigation (G&N) orientations coincide.

f. Spacecraft look angles (θ , ϕ), as defined in Figure 1, to the earth, moon, sun, and other vehicle are presented where applicable.

1.2 Trajectory Profile

The CSM and LM state vector and ephemeris data for generating the CSM solo and the docked CSM/LM attitude data were obtained from the Lunar Mission Analysis Branch of MPAD-MSC. The LM descent and ascent trajectory parameters were furnished by the Landing Analysis Branch of MPAD-MSC, while the lunar orbit rendezvous trajectory parameters were furnished by the Orbital Mission Analysis Branch of MPAD-MSC. The complete lunar orbit phase of the mission was precision integrated on the Apollo Reference Mission Program, Version ARM08. Launch date for the mission is November 14, 1969, at 11:22:00 a.m., eastern standard time, with a 72-degree launch azimuth and a Pacific translunar injection (TLI) on the first opportunity.

Translunar and transearth flight times are approximately 81 hours and 72 hours, respectively. The lunar orbit phase consists of 45 revolutions (approximately 89 hours) in lunar orbit including a LM lunar stay time of approximately 32 hours.

1.3 Attitude Data Generation

For the CSM/LM docked and the CSM solo operations, the Apollo Mission Attitude Requirements (AMAR) Program was used to produce the attitude data required to define the nominal mission attitude timeline. For the two-vehicle (CSM and LM active operations) portion of the mission, the ARM08 Program was used to produce the attitude data. For the purpose of data generation, instantaneous maneuvers were assumed in reorienting the spacecraft from an existing attitude. Appropriate time intervals are provided for finite reorientations in the timeline. The maneuver times are representative only, and they are not intended to reflect actual rates. The REFSMMAT's shown in Table II were used in the generation of these data.

Spacecraft attitude data has been supplied to the Flight Planning Branch of FCSD-MSC for inclusion in the Apollo 12 flight plan. In addition, computer tapes of the mission trajectory and attitude profile are available. Request for these tapes should be made through the Mission Planning Support Office of MPAD-MSC.

1.4 Spacecraft Attitude Constraints

The CSM and LM, both in the docked and undocked configurations, are subject to attitude restrictions throughout the mission. In general, these restrictions are imposed by subsystem requirements, mission requirements, or geometry limitations.

The major constraints considered in defining the H-1 mission spacecraft attitude timeline are enumerated below. Unless noted otherwise, the constraints are relevant to specific events or operations. Violation of any constraint is noted in the attitude timeline discussion (Sections 3, 4, 5, and 6).

1. Earth Orbit and Cislunar Phases

a. The S-IVB/SLA/CSM/LM configuration in earth orbit coast should maintain a local horizontal attitude hold with the CSM plus X-axis forward along the direction of motion and the crew heads down (CSM minus Z-axis towards the earth). This local attitude hold should be established following parking orbit insertion and maintained until just prior to the translunar injection burn.

b. CSM tracking, telemetry, and voice are required during transposition, docking, and ejection.

c. CSM tracking, command, telemetry, and voice are required for 1 hour following ejection.

d. CSM IMU gimbal lock must be avoided for all events and operations in the cislunar phase. For the H-1 mission, IMU gimbal lock is assumed to occur when the angle between the outer and inner gimbal axes is less than 45 degrees.

e. During docking with no artificial lighting, the sun must lie between 90 and 150 degrees of the CSM positive X-axis.

f. Pitch and roll maneuvers required for transposition and docking are performed at 5 degrees per second.

g. CSM monitoring of the S-IVB is required for 1 hour following ejection.

h. During passive thermal control (PTC) the angle between the line of sight to the sun and the CSM Y-Z plane must be less than 30 degrees. A roll rate between one and three revolutions per hour must also be maintained.

2. Lunar Orbit Phase

a. CSM and LM gimbal lock must be avoided for all events and operations in the lunar orbit phase. For the H-1 mission, IMU gimbal lock is assumed to occur when the angle between the outer and inner gimbal axes is less than 45 degrees.

b. CSM and LM high-gain communications are highly desirable when earth line of sight exists and the attitude does not conflict with other mission objectives.

c. During the sleep period prior to LM undocking, the CSM/LM docked attitude must provide MSFN coverage through the CSM S-band steerable antenna when earth line of sight exists. A nominal thermal environment must also be provided for the CSM RCS quads by orienting the spacecraft with respect to the sun.

d. CSM and LM IMU alignments in lunar orbit must avoid sunlight interference. For the H-1 mission, this is accomplished by scheduling these events to occur in darkness. During the alignment operation, the spacecraft attitude must provide the sextant (SXT) field of coverage with at least two reference stars from 20 to 90 degrees apart. The shaft drive axis (SDA) must be at least 20 degrees above the lunar horizon.

e. During undocked activities, CSM and LM attitudes should be favorable for VHF communications unless precluded by other requirements.

f. During CSM landmark tracking, the actual marking operation should be confined to the portion of the orbit above 35 degrees elevation angle with respect to the landmark. The CSM attitude and attitude rate should be established to allow maximum optics coverage during this time. Due to an optics system constraint, the CSM attitude rate while marking is limited to a rate less than 0.5 degree per second.

g. During terminal rendezvous and docking, at ranges greater than 50 feet the LM attitude must provide CSM visibility through the LM forward (plus Z) windows. After pitchover to the docking orientation at a range of 50 feet, CSM visibility is required through the overhead (plus X) window.

Further detail on lunar mission attitude constraints may be obtained from Reference 4.



2. SYMBOLS

AGS	abort guidance system
AMAR	Apollo Mission Attitude Requirements Program
ANT	antenna
AOS	acquisition of signal
AOT	alignment optical telescope
APS	ascent propulsion subsystem
ARM08	Apollo Reference Mission Program, Version ARM08
ATT	attitude
AUTO	automatic
CDH	constant delta altitude
CMP	command module pilot
C/O	cutoff
COAS	crew optical alignment sight
COMM	communications
CPA	closest point of approach
CSI	coelliptic sequence initiation
CSM	command and service module
DK	docked
DKNG	docking
DOI	descent orbit insertion
DPS	descent propulsion subsystem
FCSD-MSC	Flight Crew Support Division - Manned Spacecraft Center
FDAI	flight director attitude indicator

FDAIP	LM flight director attitude indicator pitch angle
g. e. t.	ground elapsed time (hr:min:sec)
G&N	guidance and navigation
HGA	high-gain antenna
HR	high resolution
IATTH	inertial attitude hold
IGA	inner gimbal angle
IGN	ignition
IMU	inertial measurement unit
INP	vehicle inertial pitch angle
JETT	jettison
LATTH	local attitude hold
LDMK	landmark
LH	local horizontal
LHP	vehicle pitch angle referenced to local horizontal orientation
LM	lunar module
LM S-BD ANT	LM S-band steerable antenna
LOI-1	first lunar orbit insertion burn
LOI-2	lunar orbit circularization burn
LOS	loss of signal
LOSM	line-of-sight maintenance
LR	landing radar
LS	landing site
MAN	manual
MGA	middle gimbal angle

MNVR	maneuver
MPAD-MSC	Mission Planning and Analysis Division - Manned Spacecraft Center
MSFN	Manned Space Flight Network
NA	not applicable
OGA	outer gimbal angle
ORBRATE	orbital pitch rate
ORDEAL	orbit rate display earth and lunar
ORDP	angular position of LM plus Z-axis referenced to local horizontal orientation (plus Z-axis pointing in the direction of motion)
PC	plane change
PDI	powered descent initiation
PHOTO	photography
R	vehicle roll angle
RCS	reaction control subsystem
REALIGN	realignment
REFSMMAT	reference to stable member coordinate transformation matrix
REV	revolution
RNDZ	rendezvous
RNG	range/ranging
RR	rendezvous radar
S/C	spacecraft
SCT	scanning telescope
SEP	separation
SPS	service propulsion system

SXT	sextant
TCA	time of closest approach
TEI	transearth injection
TPI	terminal phase initiation
TRKNG	tracking
UNDK	undock
VHF	very high frequency
Y	vehicle yaw angle

3. EARTH ORBIT

The S-IVB/SLA/LM/CSM configuration is inserted into 100-nautical mile altitude circular parking orbit by the Saturn V booster at 00:11:53 g. e. t. The booster/spacecraft attitude at insertion burn termination is inertially fixed for 20 seconds. Following this hold, the S-IVB attitude control system positions the S-IVB (and CSM) X-axis along the local horizontal in the direction of motion. The CSM plus Z-axis is directed along the current position vector. This alignment (which is heads down for the crew) is maintained by an S-IVB orbital pitch rate during the earth orbit phase of the mission. This attitude provides communication coverage during passes over manned space flight network (MSFN) stations. The local attitude hold is terminated prior to ignition of the TLI burn which occurs at 02:47:20 g. e. t. during the second earth parking orbit revolution. Attitude control for the burn is also through the S-IVB control system.

Spacecraft position and attitude data for the earth orbit phase of the mission are listed in Table I (a). The IMU gimbal angle data for this phase apply to the launch pad alignment of the spacecraft IMU. The transformation matrices (REFSMMAT) for this and other nominal IMU alignments pertaining to various mission phases are given in Table II. Alignment of the IMU to a new inertial reference is noted in both the discussion and the tabular IMU gimbal angle data.



4. TRANSLUNAR ATTITUDE PROFILE

Presented in this section are major translunar events for which specific attitude sequences have been determined. These events include the transposition, docking and ejection sequence, the S-IVB evasive maneuver, the PTC periods, and the pre-LOI sequence. Table I (b) lists the spacecraft attitude data for the translunar coast phase, which begins at TLI burn termination (02:52:44 g. e. t.) and ends at lunar orbit insertion (LOI-1) burn ignition (83:28:47 g. e. t.). Preflight attitudes for IMU alignments, the first, third, and fourth midcourse corrections, and cislunar navigation cannot be predicted precisely; attitude data for these events are therefore not available. The nominal mission event times are indicated, however, as obtained from Reference 2. The second midcourse or hybrid maneuver is nominally a nonzero magnitude burn, and is included. A schematic representation of the major cislunar events is shown in Figure 2.

4.1 Post-TLI Sequence of Events

Termination of the TLI burn occurs at 02:52:44 g. e. t. The S-IVB attitude control system maintains the burnout attitude inertially fixed for 20 seconds following thrust termination. A local horizontal attitude hold is then established by the S-IVB with the CSM plus X-axis forward in the direction of motion and the CSM plus Z-axis up along the local vertical. At TLI cutoff plus 15 minutes, the S-IVB orients the spacecraft/booster configuration to the required inertial attitude for transposition and docking. This attitude, in terms of the local horizontal orientation at TLI cutoff plus 15 minutes, consists of a positive 120-degree pitch, a negative 30-degree yaw, and a roll of 180 degrees for the S-IVB. The CSM orientation is identical except for the roll orientation which is 0 degree for the CSM. With this orientation, which is taken from Reference 5, the S-IVB and CSM are prepared for the transposition and docking maneuver sequence initiated at TLI cutoff plus 25 minutes with CSM/S-IVB separation. A CSM RCS plus X-axis translation burn of 0.8 foot per second provides the CSM/S-IVB separation rate. Approximately 2 minutes later, (TLI cutoff plus 27 minutes), the CSM nulls the separation rate and pitches 180 degrees to prepare for the CSM/LM docking maneuver. After aligning to the proper CSM/LM docking index (LM plus Z-axis in the CSM minus Z-plus Y quadrant 60 degrees (± 10 degrees) from the CSM minus Z-axis), the CSM closes with the LM (and S-IVB) and completes the docking maneuver. LM ejection is accomplished at approximately TLI plus 80 minutes after which the CSM orients to a local horizontal attitude of 354.2, 345.0, and 92.6 degrees (pitch, yaw, and roll) by 04:16:00 g. e. t. for the S-IVB evasive maneuver. This attitude is designed to allow viewing the S-IVB through the hatch window and also aligns the CSM/LM in the backup RCS evasive attitude for a +X RCS burn in the event the S-IVB APS evasive maneuver is not performed at 04:24:00 g. e. t. as planned. By 04:28:00 g. e. t., the CSM has maneuvered to a local horizontal attitude of

244.2, 45.3, and 124.0 degrees (pitch, yaw, and roll), while maintaining line of sight to the S-IVB. A local horizontal hold is then maintained to keep the S-IVB in view until the S-IVB slingshot maneuver, which occurs at 04:57:00 g.e.t. The CSM attitudes for observation of the S-IVB evasive maneuver are defined in Reference 6.

The CSM IMU realignment and cislunar navigation sightings are performed beginning at 05:30:00 g.e.t. The navigation sightings consist of five sets of star-earth horizon sightings. The first midcourse correction is nominally zero in magnitude, but is designed to reduce trajectory dispersions if necessary. The hybrid maneuver, or second midcourse correction, has a ΔV of 63.8 feet per second. This burn is included so that all TLI burns for the H-1 launch window can be performed over the Pacific Ocean. The third and fourth midcourse corrections are nominally zero.

4.2 Passive Thermal Control

The translunar coast period following the post-TLI events and ending at the time for the last translunar midcourse correction consists, in terms of spacecraft attitude, primarily of maintaining an acceptable thermal environment for the various spacecraft subsystems. This nominal thermal environment is provided by the PTC mode which involves spinning the spacecraft about the body X-axis at approximately one revolution every 20 minutes. The spacecraft is aligned initially so that the X-axis is normal (within ± 30 degrees) to the sun, thereby equalizing the solar heat incidence when the spin is induced. Once the spin rate is established, all RCS control jets may be disabled (true PTC), or the pitch-yaw control may be maintained in wide deadband which is planned for mission H-1. Simulation of PTC periods for this document assumed exact attitude control in all channels (pitch, yaw, and roll). The REFSMMAT used in establishing the spacecraft PTC orientation is defined in Table II. The IMU Y-axis pointing was determined so that the possibility of gimbal lock occurring for transearth midcourse burns is minimized. The PTC attitude is also designed to optimize spacecraft-MSFN communications by orienting the spacecraft X-axis as near the normal to earth line of sight as possible while satisfying the other attitude constraints noted previously.

4.3 Pre-LOI Events

The pre-LOI sequence of events is assumed to begin at approximately 77:30:00 g.e.t. when the CSM IMU is aligned to the landing site REFSMMAT. This inertial IMU alignment corresponds to a local horizontal attitude of 90.0, 0.0, and 0.0 degrees (pitch, yaw, and roll) with the nominal (assumed) time of LM touchdown and descent orbit approach azimuth. The IMU realignment is followed at approximately 78:25:18 g.e.t. by a midcourse correction, if required. Another IMU realignment occurs at 81:10:00 g.e.t.

The spacecraft maneuvers to the LOI-1 burn attitude rolled 120 degrees at 81:55:00 g.e.t. This attitude allows for CSM S-band HGA communications while the pre-LOI systems checks are performed. At 83:03:00 g.e.t., the spacecraft rolls back to the burn attitude and this attitude is held inertially fixed until LOI-1 ignition.



5. LUNAR ORBIT ATTITUDE PROFILE

This section contains a brief description of the lunar orbit attitude profile. The events are discussed in chronological order with only those mission events which affect the attitude profile being mentioned.

The mission H-1 lunar orbit profile may be divided into five major sections:

1. First lunar orbit insertion burn (LOI-1) cutoff to CSM/LM undocking
2. CSM/LM undocking to LM landing
3. LM landing to LM lift-off (CSM solo operations)
4. LM lift-off to CSM/LM docking
5. CSM/LM docking to TEI burn ignition

The discussion will be divided into these sections with the first, third, and fifth sections being discussed revolution by revolution, while the second and fourth sections are discussed according to major events. For the purpose of this document, a vehicle revolution will be referenced to the lunar surface. The first vehicle revolution is assumed to start at LOI-1 burn cutoff and end at 180 degrees selenographic longitude. All other revolutions start and end at 180 degrees selenographic longitude except the forty-fifth revolution which ends at transearth injection (TEI) burn ignition.

Detailed trajectory and attitude data for the lunar orbit phase of the mission are presented in Table I (c).

5.1 LOI-1 Burn Cutoff to CSM/LM Undocking

Detailed trajectory and attitude data for the LOI-1 burn cutoff to CSM/LM undocking portion of the lunar orbit are presented in Table I (c), Part 1.

5.1.1 First revolution (Figure 3). - The LOI-1 burn is designed to insert the CSM/LM into a 60- by 170-nautical mile elliptical parking orbit around the moon. The burn is performed by the CSM service propulsion system (SPS) engine. The CSM/LM is in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The CSM/LM is held inertially fixed until the vehicle is maneuvered to the lunar surface observation attitude just prior to acquisition of Manned Space Flight Network (MSFN) line of sight. This vehicle attitude is maintained

inertially fixed until approximately 13 minutes later when an orbital pitch rate is begun. The CSM attitude, with respect to the local horizontal orientation, is a pitch of 315 degrees and a roll of 180 degrees. This lunar surface observation attitude allows observation of the CSM/LM ground-track through the CSM hatch window and oblique views of the lunar surface through the CSM side windows. This vehicle attitude is held locally fixed until approximately 18 minutes prior to entering lunar umbra. At this time, the local attitude hold is terminated, and the vehicle attitude is maintained inertially fixed through the completion of the first revolution. The CSM S-band high-gain antenna (HGA) communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.2 Second revolution (Figure 4). - At the beginning of the second revolution, the spacecraft is in an inertially fixed S-band HGA communications attitude. This vehicle attitude is maintained inertially fixed to allow for a CSM inertial measurement unit (IMU) realignment. The IMU realignment to the landing site REFSMMAT occurs approximately 2 minutes after the CSM/LM enters darkness. Approximately 2 minutes prior to loss of MSFN line of sight, the CSM/LM is maneuvered to the LOI-2 burn attitude. This attitude is held inertially fixed through the completion of the second revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to the maneuver to the LOI-2 burn attitude.

5.1.3 Third revolution (Figure 5). - At the beginning of the third revolution, the CSM/LM is in the inertially fixed LOI-2 burn attitude. This attitude is held inertially fixed until the LOI-2 burn is performed approximately 17 minutes prior to acquisition of MSFN line of sight. This circularization burn transforms the initial elliptical parking orbit into a 60-nautical mile circular orbit. The SPS burn is performed with the CSM/LM in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The LOI-2 burn cutoff attitude is maintained inertially fixed until approximately 1 minute prior to acquisition of MSFN line of sight. At this time, the CSM/LM is maneuvered to the landmark tracking attitude rolled 180 degrees for communications. This attitude is maintained inertially fixed to allow for a CSM IMU realignment to the landing site REFSMMAT, which occurs at the time the CSM/LM enters darkness. This vehicle attitude is held inertially fixed through the completion of the third revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.4 Fourth revolution (Figure 6). - At the beginning of the fourth revolution, the spacecraft is in the inertially fixed landmark tracking attitude rolled 180 degrees for communications. This attitude is held inertially fixed until about 7 minutes after acquisition of MSFN line of sight. At this time, the vehicle is rolled 180 degrees to the mode I landmark tracking attitude for site H-1 and is held inertially fixed. Table III presents the lunar landmark tracking sites for mission H-1.

As explained in Section 5.1.5, the mode I attitude is such that the spacecraft will be pitched 2 degrees below the local horizontal at 35 degrees elevation east of the landmark (approximately 90 seconds from the closest point of approach (CPA) to the landmark). The spacecraft is then given a -0.3-degree-per-second pitch rate. The landmark remains in the optics field of coverage for about 3 minutes. The pitch rate is maintained for 16 minutes until the spacecraft is in the sleep pitch attitude. The CSM/LM is then rolled 126 degrees to the sleep attitude which is held inertially fixed through the completion of the fourth revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the 180-degree roll to the landmark tracking attitude and from the roll of 126 degrees to the sleep attitude to loss of MSFN line of sight.

5.1.5 Docked lunar landmark tracking (Figures 7, 8, and 9). - The geometry for lunar landmark tracking is defined by Figures 7 and 8. The acceptable marking region is defined as the area from 35 degrees elevation on either side of the landmark. The period of time the spacecraft remains in the acceptable marking region is approximately 3 minutes. Marks taken within this region must be equally spaced and at least 25 seconds apart. Five marks are required on each landmark, with a minimum time of 100 seconds required between the first and the last mark. The primary consideration is that the marks be taken over a wide spread of elevation geometry. The scanning telescope (SCT) will be used to acquire the landmark, and the sextant (SXT) will be used to track the landmark.

The landmark tracking attitude mode to be used for docked lunar landmark tracking is a mode I type. A complete discussion of the lunar landmark tracking attitude modes available for landmark tracking is presented in Reference 7. Mode I tracking consists of an inertial attitude hold with the CSM X-Z plane approximately in the lunar orbit plane. As the spacecraft approaches the landmark, a pitch rate is added to allow the landmark to remain in the optical fields of coverage while the spacecraft is in the acceptable marking region. The geometry for the particular mode I tracking used is presented in Figure 9. The initial inertial attitude is such that the CSM is pitched 2.1 degrees below the local horizontal orientation approximately 90 seconds before the closest point of approach (CPA). A -0.3-degree-per-second pitch rate is added at 35 degrees elevation and is maintained until the vehicle exits the acceptable marking region approximately 90 seconds after the CPA. At the termination of the pitch rate, the CSM X-axis lies approximately 47 degrees below the local horizontal. The landmark enters the SCT field of coverage 148 seconds before the CPA (21 degrees elevation) and enters the SXT field of coverage 112 seconds before the CPA (28.2 degrees elevation). The landmark is still in both the SXT and SCT fields of coverage when the vehicle exits the acceptable marking region approximately 90 seconds after the CPA.

To aid the astronaut in landmark tracking, two times, (T_1 and T_2), will be updated to the astronaut in real time. T_1 , which is primarily an astronaut alert time, is the g. e. t. when the spacecraft comes across the

landmark topocentric horizon. T_1 occurs approximately 390 seconds before the CPA to the landmark. T_2 is the g.e.t. to start the pitch rate and occurs approximately 90 seconds before the CPA.

As a result of the maximum rate limits of the optics shaft and trunnion angles, there are certain zones in the optical coverage area where the optics line of sight cannot keep up with the coverage of the landmark. This occurs when the groundtrack of the optics shaft axis passes close to the landmark. In mission H-1, the optical blind zone will be avoided by rolling the spacecraft so that the minimum trunnion angle is at least 10 degrees. This maneuver will be added in real time and is not simulated here. The required roll is small, and the times given above are not appreciably affected. The optics shaft and trunnion angles are the optics angles required to center the optics line of sight along the vehicle to landmark line of sight at 35 degrees elevation before the CPA. Detailed shaft and trunnion plots are available for each landmark but will not be presented in this document.

5.1.6 Fifth revolution (Figure 10). - At the beginning of the fifth revolution, the spacecraft is in the inertially fixed lunar orbit sleep attitude. An 8.5-hour sleep period is started approximately 32 minutes after acquisition of MSFN line of sight. The lunar orbit sleep attitude is maintained inertially fixed through the completion of the fifth revolution.

5.1.7 First lunar orbit sleep period (Figures 11, 12, 13, 14, and 15). - The inertial lunar orbit sleep geometry is shown in Figure 11. An inertial attitude hold is used to minimize reaction control subsystem (RCS) propellant usage and to provide the required continuous CSM S-band HGA communications when line of sight to the earth exists. Also, RCS quad cold problems must be avoided. The thermal constraints may be avoided by rolling the spacecraft so that quad D is pointed at the sun (after LOI-1 the RCS tank behind quad D is almost full and acts as a heat sink). To decrease the amount of sunlight incident on quad D, the spacecraft X-axis is pitched 60 degrees from the normal to the sun. This sleep attitude was flown on missions F and G and proved to work satisfactorily. The inertial attitude is such that the CSM is pitched 300 degrees and rolled 126 degrees from the local horizontal at the subsolar point. The attitude is kept in G&N attitude hold with a ± 10 -degree deadband throughout the lunar orbit sleep period. The lunar orbit sleep period lasts approximately 8.5 hours, being terminated in the ninth revolution. The inertial sleep attitude is maintained until the maneuver for LM S-band steerable antenna check in the tenth revolution.

5.1.8 Tenth revolution (Figure 16). - At the beginning of the tenth revolution, the spacecraft is in the inertially fixed lunar orbit sleep attitude. Approximately 8 minutes after entering lunar umbra, the CSM/LM is maneuvered to the inertial landmark tracking attitude for site 193, rolled 240 degrees to give both CSM S-band HGA communications and LM S-band steerable communications. This vehicle attitude satisfies the attitude requirements for a CSM IMU alignment to the updated landing site

REFSMMAT which occurs approximately 2 minutes prior to loss of MSFN line of sight. This attitude is maintained inertially fixed through the completion of the tenth revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight. The LM S-band steerable communications will be available from the maneuver from the sleep attitude to loss of MSFN line of sight.

5.1.9 Eleventh revolution (Figure 17). - At the beginning of the eleventh revolution, the spacecraft is in the inertially fixed landmark tracking attitude rolled 240 degrees. This attitude is maintained inertially fixed through the completion of the eleventh revolution. The CSM S-band HGA communications and LM S-band steerable communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.10 Twelfth revolution (Figure 18). - At the beginning of the twelfth revolution, the spacecraft is in the inertially fixed landmark tracking attitude rolled 240 degrees. This attitude is maintained inertially fixed until about 24 minutes after acquisition of MSFN line of sight when the vehicle is rolled 120 degrees to the mode I landmark tracking attitude. This attitude is held inertially fixed until a 35-degree elevation angle is attained east of landmark site 193. At this time a -0.3-degree-per-second pitch rate is initiated. This pitch rate is maintained 5.4 minutes until the pitch for the abort guidance system (AGS) calibration attitude is attained. The CSM/LM is then yawed and rolled to the AGS calibration attitude which is an inertial pitch of 157.5 degrees, yaw of 22.5 degrees, and roll of 7.5 degrees for the CSM. This attitude is held inertially fixed through the completion of the twelfth revolution. The CSM S-band HGA communications and LM S-band steerable communications will be available from acquisition of MSFN line of sight to the 120-degree roll to the landmark tracking attitude. It is also available from the maneuver to AGS calibration attitude to loss of MSFN line of sight.

5.1.11 Thirteenth revolution to undocking (Figure 19). - At the beginning of the thirteenth revolution, the spacecraft is in the inertially fixed AGS calibration attitude. This attitude is maintained inertially fixed until approximately 4 minutes prior to acquisition of MSFN line of sight when the spacecraft is maneuvered to the undocking attitude.

5.2 CSM/LM Undocking to LM Landing

Detailed trajectory and attitude data for both the CSM and LM during the undocking to landing portion of the lunar orbit are presented in Table I (c), Part 2.

5.2.1 CSM/LM undocking to DOI burn ignition (Figure 19). - The CSM/LM undocking occurs at 107:54:22 g. e. t., which is approximately 30 minutes prior to the CSM - RCS separation burn. This is the first time during the mission that the LM operates as a separate spacecraft. The

procedure calls for a "soft undocking." That is, the physical separation of the two vehicles must not perturb their respective orbital states. After the latches that connect the two vehicles are opened, the CSM becomes the active vehicle and moves 40 feet away from the LM. From this distance, the command module pilot (CMP) will visually inspect the LM for any structural damage that would prevent the LM from continuing the mission.

At undocking, the orientation of the docked vehicles is such that the CSM/LM longitudinal (X) axis lies along the radius vector with the CSM above the LM. The CSM is pitched 90 degrees below and rolled 180 degrees from the local horizontal orientation. This attitude is the CSM inertial separation burn attitude. The CSM attitude is held inertially fixed throughout the undocking to separation phase of the mission. During the undocking and subsequent visual inspection of the LM, the CSM is above the LM allowing the CMP a view of the LM unhampered by the sun. After physical separation at undocking, the LM maneuvers (pilot yaw left 60 degrees, pitch up 90 degrees) to an attitude allowing the crew to see the CMP. The LM attitude is held inertially fixed throughout the inspection to separation phase of the mission. Both CSM and LM attitudes are favorable for HGA and steerable S-band communications, respectively, during the undocking and subsequent inspection.

The CSM separation burn ignition occurs at 108:24:22 g. e. t. The burn is performed 180 degrees in central angle prior to the point of descent orbit insertion (DOI) and is designed to provide adequate separation distance between the CSM and LM at DOI. Separation is accomplished by the CSM minus Z-axis RCS thrusters applying a ΔV of 2.5 feet per second radially downward.

At separation, a CSM attitude maneuver should not be required since the CSM undocking attitude was the preferred inertial attitude for separation burn ignition. The CSM attitude is held inertially fixed during the burn. At separation, the LM maneuvers to an attitude that allows the crew to visually monitor the CSM after the separation burn. This attitude aligns the plus X-axis of the LM along the line of sight to the CSM at separation burn ignition and is held inertially fixed during the burn. Both CSM and LM attitudes are favorable for HGA and steerable S-band communications, respectively, during the separation burn.

The time between separation and DOI is spent in preparation for the DOI burn. Both the CSM and LM have two major activities to perform in this mission phase. The first is vehicle-to-vehicle tracking. The CSM attitude necessary to track the LM aligns the center of common coverage of the CSM SXT and RR transponder along the CSM/LM line of sight. The center of common coverage lies 35 degrees from the CSM X-axis toward the CSM plus Z-axis. The preferred CSM/LM line of sight is maintained automatically during tracking periods by a variable pitch maneuver controlled by the CSM guidance and navigation (G&N) system. The LM attitude necessary to track the CSM aligns the LM RR and tracking light along the LM/CSM line of sight. The center of coverage for both the RR and tracking light lies along the LM plus Z-axis. The preferred LM/CSM line of

sight is maintained manually during the tracking periods by a pitch maneuver at the discretion of the LM crew.

The first CSM/LM tracking period begins at 108:31:00 g. e. t. and continues for approximately 5 minutes. Upon completion of the tracking period, the CSM will be held inertially fixed until 108:44:00 g. e. t. The first LM/CSM manual tracking period begins at 108:36:00 g. e. t. and ends at 108:44:00 g. e. t. Both CSM and LM attitudes are favorable for HGA and steerable S-band communications, respectively.

The second major activity in this mission phase for both the CSM and LM is an IMU realignment prior to DOI. At 108:44:00 g. e. t., each spacecraft is maneuvered to an attitude that provides a suitable starfield to perform the realignment. Each spacecraft attitude is then held inertially fixed. The LM realignment will begin at 108:45:00 g. e. t. The CSM realignment will begin at 108:50:00 g. e. t. The CSM orientation is not favorable for HGA communications in the IMU realignment attitude. The LM attitude is favorable for steerable S-band communications until loss of MSFN line of sight at 108:55:46 g. e. t.

At 109:06:00 g. e. t., the LM maneuvers to the inertial DOI burn attitude which is an in-plane, retrograde, face-up orientation. Four minutes later, at 109:10:00 g. e. t., the CSM begins its second CSM/LM tracking period and continues automatic tracking throughout the DOI burn.

The DOI burn ignition occurs at 109:23:00 g. e. t. The burn is performed by the LM descent propulsion system (DPS) by applying a ΔV of 72.1 feet per second in a targeted direction to achieve a 59.3- by 8.3-nautical mile Hohmann transfer orbit.

5.2.2 DOI burn cutoff to PDI burn ignition (Figure 20). - The LM DOI burn cutoff occurs at 109:23:28 g. e. t. The LM maintains the burn attitude in an inertial hold until 109:25:00 g. e. t. At this time, the second LM/CSM tracking period begins and the preferred LM/CSM line of sight is maintained manually until 109:32:00 g. e. t. The LM attitude at the end of the tracking period is held inertially fixed until the maneuver to the inertially held powered descent initiation (PDI) attitude at 109:38:00 g. e. t. The LM PDI attitude is favorable for steerable S-band communications after acquisition of MSFN line of sight at 109:42:33 g. e. t.

The primary CSM activity in this mission phase is LM tracking. The automatic tracking period initiated prior to DOI is continued until 109:25:00 g. e. t. At this time, the automatic tracking is interrupted for approximately 1 minute to perform a G&N function. The CSM resumes automatic tracking at 109:26:00 g. e. t. and maintains the preferred CSM/LM line of sight until acquisition of MSFN line of sight at 109:41:59 g. e. t. The CSM is rolled 80 degrees at acquisition of MSFN line of sight for HGA communications. This attitude is held inertially fixed until 109:47:00 g. e. t. when the CSM reverses the 80-degree roll maneuver and

loses HGA communications. At 109:50:00 g.e.t., the CSM begins automatic tracking and continues preferred CSM/LM line-of-sight maintenance until 110:12:00 g.e.t. At this time, the CSM discontinues automatic tracking but continues the preferred CSM/LM line-of-sight maintenance by initiating manual pitch maneuver control at the discretion of the CMP.

5.2.3 PDI burn ignition to LM landing (Figure 21). - PDI occurs at 110:20:00 g.e.t., when the LM DPS engine is ignited for the second time in the mission. The powered descent is a guided burn from perilune to the landing site. The LM steerable S-band communications are available throughout the powered descent.

During the powered descent, the CSM continues the manual CSM/LM line-of-sight maintenance initiated prior to PDI until the LM has landed. The CSM HGA communications will not be available during the LM powered descent. The HGA communications will be reestablished after LM landing when the CSM discontinues CSM/LM line-of-sight maintenance and maneuvers to an IMU realignment attitude.

5.3 LM Landing to LM Lift-off (CSM Solo Operations)

Detailed trajectory and attitude data for the CSM solo operations from LM landing to LM lift-off are presented in Table I (c), Part 3.

5.3.1 LM landing to initiation of fifteenth revolution (Figure 22). - Following LM touchdown which occurs at 110:31:19 g.e.t., the CSM is maneuvered to an IMU realignment attitude in preparation for the IMU realignment to the landing site REFSMMAT, which occurs approximately 11 minutes after the CSM enters darkness. This attitude is held inertially fixed through the completion of the fourteenth revolution. CSM S-band HGA communications will be available from LM touchdown until CSM loss of MSFN line of sight.

5.3.2 Undocked lunar landmark tracking (Figure 23). - During the undocked landmark tracking periods, LM blockage, which obscured a portion of the CSM optics during docked sightings, is no longer a problem. Therefore, a much simpler mode of landmark tracking may be used on the undocked sightings. Mode III type landmark tracking will be used for the undocked landmark sightings (Reference 7). The spacecraft attitude, with respect to the local horizontal orientation during undocked sightings, is a pitch of 338 degrees. This attitude is held locally fixed throughout the tracking period. The geometry of a mode III type landmark tracking is shown in Figure 23. The landmark remains in the SXT field of coverage for approximately 146 seconds within the acceptable mark region. It should be pointed out that additional tracking time can be made available by adding a small pitch rate near the end of the tracking period, although there should be adequate time for the required five marks. The optical blind zone constraint may be satisfied, as in docked sightings, by rolling the spacecraft as the landmark is approached to assure a minimum trunnion angle of at least 10 degrees.

5.3.3 Fifteenth revolution (Figure 24). - At the beginning of the fifteenth revolution, the CSM is in the inertially fixed IMU realignment attitude. Approximately 20 minutes after acquisition of MSFN line of sight, the CSM is maneuvered to the undocked landmark tracking attitude for landmark tracking on the lunar landing site landmark (site 193). The CSM attitude, with respect to the local horizontal orientation, is a pitch of 338 degrees. This attitude is held locally fixed through the completion of the landmark tracking. Upon completion of the tracking, the local hold is terminated and the CSM is rolled 180 degrees to regain CSM S-band communications. This attitude is maintained inertially fixed through the completion of the fifteenth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight except while the CSM is in the lunar landmark tracking attitude.

5.3.4 Sixteenth revolution (Figure 25). - At the beginning of the sixteenth revolution, the CSM is in the inertially fixed HGA communications attitude. This attitude is maintained inertially fixed until approximately 22 minutes after acquisition of MSFN line of sight. At this time, the CSM maneuvers to a SXT oblique-view tracking attitude to track the LM. The spacecraft attitude, with respect to the local horizontal orientation, is a pitch of 0 degree. This attitude is held locally fixed throughout the tracking period. Upon completion of the tracking, the local hold is terminated and the CSM is rolled 180 degrees to regain CSM S-band HGA communications. This attitude is maintained inertially fixed through the completion of the fifteenth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight except while the CSM is in the LM tracking attitude.

5.3.5 Seventeenth revolution (Figure 26). - At the beginning of the seventeenth revolution, the CSM is in the inertially fixed HGA communications attitude. This attitude is maintained inertially fixed through the completion of the seventeenth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.3.6 Eighteenth revolution (Figure 27). - At the beginning of the eighteenth revolution, the CSM is in the inertially fixed HGA communications attitude. This attitude is maintained inertially fixed until approximately 9 minutes prior to entering darkness. The CSM is then yawed 45 degrees for the IMU realignment to the plane change 1 heads-up REFSMMAT, which occurs approximately at the time the CSM enters darkness. The plane change 1 heads-up REFSMMAT represents an out-of-plane IMU alignment. The 45-degree yaw allows the transition from the in-plane IMU alignment to the out-of-plane IMU alignment without encountering IMU gimbal lock. This attitude is maintained inertially fixed until approximately 2 minutes prior to completion of the eighteenth revolution. At this time, the CSM is maneuvered to the plane change 1 burn attitude. This attitude is maintained inertially fixed through the completion of the eighteenth revolution. The CSM S-band HGA communications will be

available from the acquisition of MSFN line of sight until loss of MSFN line of sight.

5.3.7 Nineteenth revolution (Figure 28). - At the beginning of the nineteenth revolution, the CSM is in the inertially fixed plane change 1 burn attitude. This attitude is maintained until the plane change 1 burn, which occurs at 119:47:02 g. e. t. The plane change 1 burn is a CSM SPS burn designed to change the plane of the CSM orbit so that the LM is in the CSM orbit plane at lift-off. The CSM attitude at burn ignition, with respect to the local horizontal orientation, is a pitch of 221.6 degrees, yaw of 85.5 degrees, and a roll of 138.5 degrees. This attitude is held inertially fixed until burn cutoff.

Following the plane change 1 burn cutoff, the CSM is maneuvered to an IMU realignment attitude in preparation for the IMU realignment to the lift-off REFSMMAT, which occurs approximately 1 minute after the CSM enters darkness. The CSM is yawed and rolled to the IMU realignment attitude which is an inertial pitch of 273.0 degrees, yaw of 39.0 degrees, and roll of 0.0 degree. The resultant attitude satisfies the attitude requirements for a CSM IMU realignment to the lift-off REFSMMAT and is also compatible with S-band HGA communications. This attitude is maintained inertially fixed until approximately 15 minutes after loss of MSFN line of sight, at which time the CSM maneuvers to the lunar orbit sleep attitude. This attitude is then held inertially fixed through the completion of the nineteenth revolution. The CSM S-band HGA communications will be available from the acquisition of MSFN line of sight until the loss of MSFN line of sight.

5.3.8 Second lunar orbit sleep (Figures 29, 30, 31, 32, 33, and 34). - The CSM attitude during the second lunar orbit sleep period is approximately the same attitude (5-degree change in roll angle) as that for the first lunar orbit sleep period as discussed in Section 5.1.7 and as illustrated in Figure 11. The inertial lunar orbit sleep attitude is such that the CSM is pitched 300 degrees and rolled 121 degrees from the local horizontal orientation at the subsolar point. The longitude used in calculating the attitude is the longitude at the subsolar point in the twenty-second revolution. The inertial sleep attitude is maintained through the completion of the twenty-fifth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight in each applicable lunar orbit revolution.

5.3.9 Twenty-sixth revolution (Figure 35). - At the beginning of the twenty-sixth revolution, the CSM is in the inertially fixed lunar orbit sleep attitude. This attitude is maintained inertially fixed until approximately 19 minutes prior to entering darkness. At this time, the CSM is maneuvered to the mode III type landmark tracking as discussed in Section 5.3.2 and illustrated in Figure 23. Landmark tracking will be made on site Lansberg A. The spacecraft attitude, with respect to the local horizontal orientation, is a pitch of 338 degrees. This attitude is held locally fixed throughout the tracking period. Upon completion of the tracking, the local

hold is terminated and the CSM is rolled 180 degrees to regain CSM S-band HGA communications. This attitude is maintained inertially fixed through the completion of the twenty-sixth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight except while the CSM is in the landmark tracking attitude.

5.3.10 Twenty-seventh revolution (Figure 36). - At the beginning of the twenty-seventh revolution, the CSM is in the inertially fixed HGA communications attitude. This attitude is maintained inertially fixed until approximately 1 minute after entering sunlight. The CSM is then maneuvered to the S158 photography attitude. The spacecraft attitude, with respect to the local horizontal orientation, is a pitch of 213 degrees. This attitude points the hatch window at the nadir. The attitude is held locally fixed through the completion of the twenty-seventh revolution. The CSM S-band HGA communications will be available from approximately 20 minutes after the acquisition of MSFN line of sight until the loss of MSFN line of sight.

5.3.11 Twenty-eight revolution (Figure 37). - At the beginning of the twenty-eighth revolution, the CSM is in the locally held S158 photography attitude. This attitude is maintained until approximately 27 minutes after acquisition of MSFN line of sight. At this time the CSM is maneuvered for S158 photography of Theophilus. The spacecraft attitude, with respect to the local horizontal orientation, is a pitch of 264 degrees, yaw of 334 degrees, and a roll of 90 degrees. This attitude is then held inertially fixed for approximately 5 minutes and results in the hatch window pointing along the line of sight to Theophilus at the time of closest approach (TCA). Upon completion of this photography, the CSM is maneuvered slightly in pitch and yaw and then held inertially fixed for approximately 10 minutes in order to perform the same type of photography of Descartes at TCA. Upon completion of the S158 photography of Descartes, the CSM is again maneuvered slightly in pitch, yaw, and roll and then held inertially fixed for approximately 6 minutes in order to perform the same type of photography of Fra Mauro at TCA. Upon completion of the S158 photography of Fra Mauro, the CSM is maneuvered back in plane to the inertial mode III landmark tracking attitude rolled 180 degrees for communications. This attitude is maintained inertially fixed to allow for a CSM IMU realignment to the lift-off REFSMMAT, which occurs at the time the CSM enters darkness. The attitude is held inertially fixed through the completion of the twenty-eighth revolution. The CSM S-band HGA communications will be available from approximately 20 minutes after the acquisition of MSFN line of sight until the loss of MSFN line of sight.

5.3.12 Twenty-ninth revolution (Figure 38). - At the beginning of the twenty-ninth revolution, the CSM is in the inertially fixed landmark tracking attitude rolled 180 degrees for communications. This attitude is held inertially fixed until approximately 25 minutes after acquisition of MSFN line of sight. At this time, the CSM is rolled 180 degrees to the mode III type landmark tracking attitude as discussed in Section 5.3.2 and illustrated in Figure 23. Landmark tracking will be made on site 193. The

spacecraft attitude, with respect to the local horizontal orientation, is a pitch of 338 degrees. This attitude is held locally fixed until approximately 9 minutes prior to entering darkness. At this time the CSM is maneuvered to the LM landing site mode III landmark tracking inertial attitude rolled 180 degrees for HGA communications. This attitude is maintained inertially fixed to allow for a CSM IMU realignment to the lift-off REFSMMAT, which occurs about 1 minute after entering darkness. The attitude is held inertially fixed through the completion of the twenty-ninth revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight except during the landmark tracking period.

5.3.13 Thirtieth revolution to LM lift-off (Figure 39). - At the beginning of the thirtieth revolution, the CSM is in the inertially fixed mode III landmark tracking attitude rolled 180 degrees for HGA communications. This attitude is held inertially fixed until approximately 7 minutes after acquisition of MSFN line of sight. At this time the CSM is rolled 180 degrees to the inertial mode III landmark tracking attitude (as discussed in Section 5.3.2), which is the initial LM lift-off support attitude. This attitude is held inertially fixed for about 18 minutes or until the CSM attains a pitch angle of 338 degrees from the local horizontal orientation. This attitude is then held locally fixed until a 22-degree SXT trunnion angle to the LM is attained, which occurs about 2 minutes prior to LM lift-off. At this time the locally held attitude is terminated and a manual line-of-sight maintenance is initiated by the command module pilot (CMP). At LM lift-off, the CSM attitude is a pitch of 260 degrees from the local horizontal orientation, and the CMP is still maintaining a constant line-of-sight attitude. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the initial LM lift-off support attitude. CSM S-band HGA communications are reacquired at LM lift-off.

5.4 LM Lift-off to CSM/LM Docking

Detailed trajectory and attitude data for both the CSM and LM during the LM lift-off to CSM/LM docking portion of the lunar orbit are presented in Table I (c), Part 4.

5.4.1 LM lift-off to insertion burn cutoff (Figure 40). - Ascent ignition occurs at 142:01:18 g. e. t. The powered ascent is a guided ascent propulsion subsystem (APS) burn to a 8-nautical mile perilune by 46-nautical mile apolune ellipse. The LM attitude profile during the burn provides S-band HGA communications. A 20-degree (pilot) yaw maneuver is required in order to obtain HGA - MSFN line of sight.

The CSM continues the line-of-sight maintenance maneuver established prior to lift-off through LM insertion. CSM high-gain communications are available throughout the ascent phase.

5.4.2 Insertion burn cutoff to tracking termination prior to CDH (Figure 41). - Cutoff of the APS ascent burn occurs at 142:08:28 g.e.t., with the LM trailing the CSM as required for CSM/LM rendezvous. At ascent burn termination, the LM orients to an inertially fixed attitude suitable for performing an IMU realignment which begins 5 minutes later. This realignment attitude is identical to the inertial attitude used for the LM IMU realignment prior to DOI (Revolution 13). Following the realignment, the LM orients to the heads-up RR tracking attitude in preparation for a tracking period starting 15 minutes after insertion.

The CSM at insertion is nominally 16 degrees ahead of the LM in central angle. Maintenance of a constant line of sight for LM tracking is terminated 5 minutes after insertion, and an inertial IMU realignment attitude is established. The realignment is scheduled to last 5 minutes, after which the CSM begins a period of VHF ranging. The inertial realignment attitude is defined to be the nominal initial ranging attitude.

Both spacecraft terminate tracking at 142:50:00 g.e.t. or 8 minutes prior to the coelliptic sequence initiation (CSI) burn. The LM continues line-of-sight maintenance to the CSM along the LM plus Z-axis, since the CSI thrust direction is along the LM to CSM line of sight with the LM Z-axis RCS thrusters. All nominal LM rendezvous burns (with the exception of constant delta altitude (CDH)) are similarly planned to use this line-of-sight technique.

The CSM, in preparing for the CSI maneuver, orients to the inertial mirror image (MI) CSI burn attitude. The MI burn attitude is a means of providing CSM backup capability for the LM rendezvous burns from CSI to the final braking maneuvers. The MI burn attitude involves aligning the CSM propulsion system (RCS or SPS) in a thrusting direction opposite the LM burn orientation. Ignition for the MI burn is scheduled 3 minutes after nominal time of LM CSI ignition.

The LM CSI burn occurs in darkness and out of earth line of sight for both spacecraft. CSM and LM HGA communications are acceptable in terms of the respective spacecraft attitude profile from lift-off to loss of earth line of sight.

CSI ignition occurs at 142:58:05 g.e.t., with a burn time of approximately 45 seconds. The LM attitude for the burn is pitched approximately 90 degrees above the local horizontal. This attitude corresponds to a heads-up, face-forward direction for the crew and also maintains the CSM line of sight along the LM Z-axis.

The MI burn attitude for the CSM, which is held inertially fixed until the LM CSI burn is confirmed, is retrograde and heads down (180 degrees pitch with respect to the local horizontal at LM CSI ignition). The CSM next maneuvers to prepare for a 46-minute period of VHF ranging beginning 6 minutes after the burn.

The LM continues the line-of-sight maintenance program after the CSI burn and is consequently prepared for the following RR tracking period.

The CSM and LM acquire line of sight to MSFN approximately 8 and 11 minutes, respectively, after starting the tracking period. The CSM attitude profile from MSFN acquisition to termination of the tracking period is incompatible with HGA pointing requirements. The CSM inertially holds the attitude at the end of the tracking period until the start of the next LM tracking period.

The LM HGA communications during the period from MSFN line-of-sight acquisition to tracking termination prior to CDH is acceptable. The CSM and LM terminate the tracking period at 143:50:50 g. e. t. Both vehicles inertially maintain their respective attitudes at tracking termination until the beginning of the next tracking period. For this rendezvous simulation, the CDH maneuver was not required.

5.4.3 Tracking termination prior to CDH to CSM/LM docking (Figure 42). - The CSM and LM begin another tracking period at 144:01:50 g. e. t. The tracking period is 29 minutes in duration and is followed by terminal phase initiation (TPI) burn preparations.

The CSM orients to the inertial MI TPI burn attitude at 144:30:50 g. e. t. as part of the pre-TPI operations. This attitude results in a local horizontal pitch of 209.5 degrees at TPI ignition which places the CSM/LM line of sight along the CSM X-axis. The CSM maintains the MI burn attitude until the LM TPI burn is verified as nominal.

The LM, in preparing for the TPI burn, continues CSM line-of-sight maintenance as noted previously. The burn is performed using the LM Z-axis thrusters with ignition at 144:36:50 g. e. t. and a burn time of 23 seconds. The burn occurs out of MSFN coverage and approximately 24 minutes after the LM enters darkness.

S-band HGA communications for the CSM and LM are satisfactory throughout the period from the start of tracking at 144:01:50 g. e. t. to loss of MSFN by lunar occultation.

Following the TPI burn, both spacecraft begin another period of tracking. The CSM orients to the required tracking attitude which is initially heads down. The LM is initially heads up with the Z-axis pitched up 26 degrees from the local horizontal. As a result of the LM catchup rate following TPI, the CSM and LM line-of-sight maintenance for tracking eventually produces a heads-up attitude for the CSM and a heads-down attitude for the LM. This relative orientation is maintained until MSFN acquisition. At this time, the CSM may perform a roll maneuver to provide HGA coverage of the final rendezvous and docking maneuvers. For this document, a roll maneuver of 180 degrees was executed just prior to docking.

The initial LM braking burn occurs at 145:17:39 g. e. t. with the CSM and LM 3000 feet apart. The braking maneuver at the 1-nautical mile separation distance was not required in the rendezvous simulation.

After the first braking maneuver, the CSM orients to a LM X-axis boresight alignment attitude and establishes a manual pitch rate to maintain this alignment for the remainder of the rendezvous. The LM continues the automatic RR tracking along the LM Z-axis during the coasts between the braking maneuvers. All braking burns are directed towards the CSM along the LM Z-axis.

The final LM braking burn occurs at a CSM/LM relative range of 100 feet. At cutoff, the range is approximately 90 feet and the closing rate is 0.22 foot per second. The LM continues holding the CSM line of sight along the Z-axis until a separation distance of 50 feet is attained. The LM then pitches 90 degrees to point the plus X-axis towards the CSM in preparation for docking. Both spacecraft then fly formation while the LM performs the final closing maneuvers. These include rolling (pilot yaw) the LM -60 degrees to properly align the docking index.

Docking is assumed to be completed at 145:40:00 g. e. t. Nominal HGA coverage for both the CSM and LM is provided upon MSFN line-of-sight acquisition (after the CSM performs the 180-degree roll).

5.5 CSM/LM Docking to TEI

Detailed trajectory and attitude data for the CSM/LM docking to TEI portion of lunar orbit are presented in Table I (c), Part 5.

5.5.1 CSM/LM docking to completion of thirty-second revolution (Figure 43). - The CSM/LM docking maneuver is completed at approximately 145:40:00 g. e. t. The docking attitude is maintained inertially fixed after docking through the completion of the thirty-second revolution while postdocking checks are completed and the LM crew starts preparations to leave the LM. The CSM S-band HGA and LM steerable antenna communications will be available from CSM/LM docking to loss of MSFN line of sight.

5.5.2 Thirty-third revolution (Figure 44). - At the beginning of the thirty-third revolution, the CSM/LM is in the inertially fixed docking attitude. This attitude is maintained inertially fixed until 146:51:00 g. e. t., when the docked spacecraft is maneuvered to the LM jettison attitude. The LM jettison attitude is determined such that the LM will be jettisoned in the correct inertial burn attitude for the LM ascent stage impact burn. The CSM/LM roll attitude at jettison provides CSM HGA communications at jettison and LM steerable antenna communications to LM impact. The LM is jettisoned at 147:57:00 g. e. t. At the completion of LM jettison, the CSM maneuvers to the separation burn attitude. The separation burn is a

CSM plus Z-axis RCS 1-foot-per-second burn. The burn is directly retrograde and allows the CSM to be nominally below and ahead of the LM at LM impact burn ignition. The CSM attitude at separation burn ignition consists of the CSM plus X-axis being upward along the radius vector and the minus Z-axis being in the orbit plane and pointing forward in the direction of motion. This attitude requires only a small maneuver from the jettison attitude and allows the LM to be observed from the CSM throughout the separation burn, which occurs at approximately 147:58:01 g. e. t. Following the separation burn, the CSM orients to the preferred tracking attitude for SXT tracking of the LM. The tracking is heads down to provide CSM S-band HGA communications for a longer time. Automatic line-of-sight maintenance to the LM is continued through the completion of the thirty-third revolution. CSM S-band HGA and LM steerable antenna communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.5.3 Thirty-fourth revolution (Figure 45). - At the beginning of the thirty-fourth revolution, the CSM is in the line-of-sight maintenance attitude for SXT tracking of the LM, and the LM is in the inertially fixed LM jettison attitude. The CSM maintains line-of-sight tracking of the LM until loss of sight of the LM. The LM impact burn is performed at 149:24:41 g. e. t. The burn is generally retrograde and is targeted to impact the LM near the Apollo 12 landing site. At approximately 150:00:00 g. e. t., the CSM is maneuvered to the lunar orbit rest attitude, described previously (Section 5.1.7). The rest attitude is maintained inertially fixed through the completion of the thirty-fourth revolution. CSM S-band HGA communications are available from the maneuver to the rest attitude to loss of MSFN line of sight. LM steerable antenna communications are available from acquisition of MSFN line of sight to LM impact.

5.5.4 Thirty-fifth through thirty-seventh revolutions (Figures 46, 47, and 48). - During the thirty-fifth through the thirty-seventh CSM revolutions, the CSM is in the inertially fixed lunar orbit rest attitude, as described earlier. This attitude provides CSM S-band HGA communications from acquisition of MSFN line of sight to loss of MSFN line of sight for each vehicle revolution.

5.5.5 Thirty-eight revolution (Figure 49). - At the beginning of the thirty-eight revolution, the CSM is in the inertially fixed lunar orbit rest attitude. This attitude is maintained inertially fixed until 158:06:00 g. e. t., when the CSM is yawed 45 degrees for the IMU realignment to the plane change 2 REFSMMAT, which occurs at 158:15:00 g. e. t. The plane change 2 REFSMMAT, like the plane change 1 REFSMMAT, represents an out-of-plane IMU alignment. The 45-degree yaw allows the transition from the in-plane, lift-off IMU alignment to the out-of-plane, plane change 2 IMU alignment without encountering IMU gimbal lock. This attitude is maintained inertially fixed until 158:35:00 g. e. t., when the CSM is maneuvered to the plane change 2 burn attitude. This attitude is maintained inertially fixed through the completion of the thirty-eighth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.5.6 Thirty-ninth revolution (Figure 50). - Plane change 2 burn ignition occurs at 159:01:46 g. e. t. The CSM SPS burn is made with an out-of-plane heads-up attitude. The purpose of the burn is to effect a plane change such that the CSM passes over Descartes and Fra Mauro, allowing landmark tracking and photography on these sites.

Following the plane change 2 burn, the CSM is pitched back into the orbit plane for the IMU realignment to the photography REFSMMAT, which occurs at 159:08:00 g. e. t. This realignment is using the pulse torque option; and therefore, there are no optical constraints. The pitch maneuver allows the transition from the out-of-plane, plane change 2 IMU alignment to the in-plane photography alignment without encountering IMU gimbal lock. The IMU realignment attitude is maintained inertially fixed until 159:26:00 g. e. t., when the CSM is maneuvered to the high-resolution photography attitude for high-resolution photography of Lalande.

The spacecraft attitude sequence used for landmark high-resolution photography involves an inertial attitude hold from the time of the maneuver to the high resolution photography attitude until 3 minutes prior to the time of closest approach (TCA) to the landmark. The inertial attitude is designed to allow the high-resolution camera to point along the CSM-to-landmark line of sight at TCA -3 minutes. The camera is mounted in the CSM right rendezvous window and the camera pointing is along a body-fixed line of sight in the CSM X-Z plane and is 10 degrees up from the CSM plus X-axis towards the minus Z-axis. The CSM crew optical alignment sight (COAS) is mounted in the left rendezvous window; and starting at TCA -3 minutes, the camera pointing is manually maintained along the landmark line of sight by maneuvering the spacecraft to keep the landmark in the COAS field of view. Manual line-of-sight maintenance is continued until TCA +1 minute, when the photography sequence is terminated.

Following high-resolution photography of Lalande, the CSM is maneuvered to an IMU realignment attitude for the IMU realignment to the photography REFSMMAT, which occurs at 160:20:00 g. e. t. This attitude is maintained inertially fixed through the completion of the thirty-ninth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the Lalande high-resolution photography attitude and from the maneuver to the IMU realignment attitude until loss of MSFN line of sight.

5.5.7 Fortieth revolution (Figure 51). - The CSM IMU realignment attitude is maintained inertially fixed until 160:46:00 g. e. t. The CSM is then maneuvered to a strip photography attitude. During the photography sequence, this photography attitude consists of the CSM plus X-axis being maintained downward along the local vertical and the minus Z-axis forward in the direction of motion. This attitude is maintained locally fixed until 161:54:00 g. e. t. when the local attitude hold is terminated and an inertial attitude hold is initiated. The resulting attitude is maintained inertially fixed through the completion of the fortieth revolution. CSM S-band HGA communications will be available from approximately 161:36:00 g. e. t. until loss of MSFN line of sight.

5.5.8 Forty-first revolution (Figure 52). - The CSM HGA communications attitude from the previous revolution is maintained inertially fixed until 163:16:00 g. e. t., when the CSM is maneuvered to the high-resolution photography attitude for a high-resolution photography sequence of Descartes. Following this sequence, which is the same as described earlier for Lalande, the CSM is maneuvered for a high-resolution photography sequence of Fra Mauro. At the termination of the sequence for Fra Mauro, the CSM is maneuvered to an IMU realignment attitude in preparation for the IMU realignment to the photography REFSMMAT, which occurs at 164:03:00 g. e. t. This attitude is maintained inertially fixed through the completion of the forty-first revolution. CSM S-band HGA communications are available from acquisition of MSFN line of sight to the maneuver to the Descartes high-resolution photography attitude and from the termination of the Fra Mauro high-resolution photography to loss of MSFN line of sight.

5.5.9 Forty-second revolution (Figure 53). - At the beginning of the forty-second revolution, the CSM is in the inertially fixed IMU realignment attitude. This attitude is maintained inertially fixed until 164:46:00 g. e. t., when the CSM is maneuvered to the landmark tracking attitude. During this landmark tracking period, four lunar landmarks (CP1, CP2, DE1, and FM1) are tracked using the CSM optics. The tracking procedure is the mode III orbital rate landmark tracking method described previously (Section 5.3.2). The CSM is maintained locally fixed in the landmark tracking attitude (pitched down 22 degrees from the local horizontal) until 165:42:00 g. e. t. The CSM is then rolled 180 degrees and the resulting attitude is held inertially fixed. This attitude satisfies the attitude requirements for an IMU realignment to the photography REFSMMAT at 166:05:00 g. e. t. The IMU realignment attitude is maintained inertially fixed through the completion of the forty-second revolution. CSM S-band HGA communications will be available from maneuver to the IMU realignment attitude until loss of MSFN line of sight.

5.5.10 Forty-third revolution (Figure 54). - Another period of mode III type landmark tracking is performed during this revolution on the same lunar landmarks as the previous tracking period. The IMU realignment attitude from the previous revolution is maintained inertially fixed until 166:45:00 g. e. t. The CSM is then maneuvered to the mode III landmark tracking attitude. This attitude is maintained locally fixed throughout the tracking period until 167:40:00 g. e. t. The CSM is then rolled 180 degrees and the resulting attitude is held inertially fixed through the completion of the forty-third revolution. This attitude provides CSM HGA communications until loss of MSFN line of sight.

5.5.11 Forty-fourth revolution (Figure 55). - The CSM HGA communications attitude from the previous revolution is maintained inertially fixed until 168:36:00 g. e. t. The CSM then initiates a second period of strip photography by maneuvering to a strip photography attitude. The local horizontal attitude differs slightly from that used in the previous strip photography sequence, since the CSM X-axis is pitched 12 degrees back of the local vertical while the minus Z-axis is in the orbit plane and in the direction of motion (a pitch of -102 degrees from the local horizontal

orientation). This attitude is maintained locally fixed until 169:47:00 g. e. t. , when the CSM is maneuvered for the IMU realignment attitude in preparation for the IMU realignment to the TEI REFSMMAT, which occurs at 170:02:00 g. e. t. This attitude is maintained inertially fixed through the completion of the forty-fourth revolution. CSM S-band HGA communications will be available from the maneuver to the IMU realignment attitude until loss of MSFN line of sight.

5.5.12 Forty-fifth revolution to TEI (Figure 56). - The CSM maintains the IMU realignment attitude from the previous revolution inertially fixed until 171:51:00 g. e. t. The CSM is then maneuvered to the TEI burn attitude. This attitude is maintained inertially fixed to TEI burn ignition at 172:21:15 g. e. t. The TEI burn is the major SPS burn which boosts the CSM from its approximately 60-nautical mile circular orbit into the trans-earth trajectory. The burn is performed with the CSM in an essentially posigrade attitude, with the crew heads down to afford visual reference with the lunar surface. CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the TEI burn attitude.



6. TRANSEARTH ATTITUDE PROFILE

The transearth phase of the mission begins at TEI burn termination and ends at earth atmospheric entry of the CM. Most of the major events occurring in this phase (midcourse corrections, PTC, IMU realignments, and cislunar navigation) are similar in nature to the translunar coast. Those events unique to the transearth phase, which will be discussed in this section, are the attitude sequences following TEI and prior to entry. The spacecraft attitude data for the transearth coast phase are presented in Table I (d).

6.1 Post-TEI Sequence of Events

Following TEI cutoff at 172:23:24 g.e.t., the CSM maneuvers to an inertial attitude that provides the crew with visual observation of the lunar surface. This orientation consists of the CSM plus X-axis pointing radially inward and the plus Z-axis forward in the trajectory plane. MSFN communications through the HGA at acquisition of signal is also provided with this attitude. Earth line of sight is acquired at 172:34:00 g.e.t. An IMU realignment begins at approximately 173:15:00 g.e.t. during which the IMU reference system is realigned to the PTC REFSMMAT defined in Section 4. The completion of the realignment marks the termination of post-TEI activities.

6.2 Preentry Sequence of Events

The start of the preentry attitude sequence is assumed at 239:45:00 g.e.t. when the spacecraft IMU is aligned to the entry REFSMMAT. This inertial reference system corresponds to the nominal CM entry attitude of 156 degrees positive pitch from the local horizontal at the nominal time of entry with the body X- and Z-axes in-plane. A midcourse correction is scheduled at 241:21:48 g.e.t., if required. One hour and 14 minutes later, at 242:36:00 g.e.t., the CSM orients to the entry attitude and performs a star check to verify the attitude. An IMU realignment is performed at 243:00:00 g.e.t. Upon completion of the realignment, the spacecraft prepares for the CM/SM separation maneuver which occurs at 244:10:00 g.e.t. The CM/SM separation attitude is shown in Figure 57. The spacecraft is yawed 45 degrees for separation to minimize CM/SM recontact probability during entry. After completing the separation maneuver, the CM reorients to the nominal entry attitude in preparation for entry which occurs at 244:21:48 g.e.t. The CM entry attitude is presented in Figure 58.



Table I. Spacecraft Attitude and Trajectory Data
(a) Earth Orbit

Mission Time (hr:min:sec)	Event	Geographic Position			Local Horizontal			IMU Gimbal Angles		
		Altitude * (n mi)	Latitude * (deg)	Longitude * (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)
00:11:53	Earth orbit insertion, begin inertial attitude hold	103.3	32.5	-52.5	0.0	0.0	180.0	333.1	0.6	180.8
00:12:03	Begin local attitude hold	103.3	32.5	-51.8	0.0	0.0	180.0	332.4	0.6	180.8
02:47:22	Initiate TLI burn	98.8	2.3	-176.6	0.0	0.0	180.0	57.7	0.9	179.0

* Altitude is measured with respect to the Fischer reference ellipsoid; latitude and longitude are measured positive north of the equator and east from the Greenwich meridian, respectively.

Table I. Spacecraft Attitude and Trajectory Data
(b) Translunar

Mission Time (hr:min:sec)	Event	IMU Gimbal Angles		Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		CSM HGA Pointing Angles	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Pitch (deg)	Yaw (deg)
02:52:44	TLI cutoff; S-IVB maneuver to local horizontal orientation, rolled 180 deg, local attitude hold	31.7	3.9	179.9	90.0	0.0	52.4	306.9	68.9	230.7	**
03:13:00	S-IVB maneuver to CSM/S-IVB separation attitude, inertial attitude hold	92.0	331.7	356.0	138.6	319.1	116.7	147.4	76.3	92.6	**
03:18:00	CSM/S-IVB separation	92.0	331.7	356.0	125.2	24.0	117.1	147.0	76.3	92.6	**
03:23:00	CSM null separation rate; pitch 180 deg and roll -60 deg for docking	272.0	28.3	304.0	59.7	259.8	62.8	93.1	103.7	147.4	-8 300
03:28:00	CSM/LM docking	272.0	28.3	304.0	63.7	256.6	62.7	93.3	103.7	147.4	-12 297
04:07:00	LM ejection	272.0	28.3	304.0	80.9	245.3	62.2	94.5	103.7	147.3	-23 281
04:16:00	CSM/LM maneuver to evasive maneuver attitude	277.1	343.5	96.3	84.4	85.9	90.0	311.4	148.3	349.7	**
04:24:00	S-IVB APS evasive maneuver	277.1	343.5	96.3	86.6	86.5	90.0	311.6	148.3	349.7	**
04:28:00	CSM/LM maneuver to slingshot observation attitude; maintain line of sight to S-IVB	165.8	42.5	120.2	50.7	180.2	92.0	332.5	49.0	27.1	-49 360
04:57:00	S-IVB slingshot maneuver										
05:30:00	Begin IMU realignment, change to PTC REFSMMAT										
06:00:00	Maneuver to optics calibration attitude										
06:10:00	Maneuver to star/earth horizon sighting attitude										
07:00:00	Begin PTC	90.0	0.0	0.0	112.7	198.0	99.0	345.2	90.0	282.3	-61 217
10:40:00	Terminate PTC and realign IMU										
11:52:44	First midcourse correction										
12:30:00	Resume PTC	90.0	0.0	0.0	104.6	205.1	100.6	341.5	90.0	282.5	-60 240
14:50:00	Terminate PTC and realign IMU										
15:15:00	Maneuver to optics calibration attitude										

*No line of sight

**No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(b) Translunar (Continued)

Mission Time (hr:min:sec)	Event	IMU		Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		CSM HGA Pointing Angles	
		IGA (deg)	MGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
15:30:00	Maneuver to navigation sighting attitude										
		Maneuver spacecraft as required									
16:25:00	Resume PTC	90.0	0.0	0.0	101.9	207.4	101.3	339.4	90.0	282.7	-59 246
29:30:00	Terminate PTC and realign IMU	19.3	328.3	184.7	23.6	1.7	123.7	91.1	71.3	89.8	** **
30:52:44	Second midcourse correction; $\Delta V = 63.8$ ft/sec for hybrid maneuver	19.3	328.3	184.7	23.6	1.7	123.7	91.1	71.3	89.8	** **
31:00:00	Resume PTC	90.0	0.0	0.0	92.1	214.9	104.0	328.1	90.0	284.6	-55 266
60:30:00	Terminate PTC and realign IMU										
		Maneuver spacecraft as required									
61:25:18	Third midcourse correction										
		Maneuver spacecraft as required									
61:45:00	Resume PTC	90.0	0.0	0.0	92.1	214.9	104.0	328.1	90.0	284.6	-55 266
63:20:00	Terminate PTC in TV attitude										
		Maneuver spacecraft as required									
65:00:00	Resume PTC	90.0	0.0	0.0	91.8	215.1	104.1	327.5	90.0	284.7	-53 267
77:30:00	Terminate PTC and realign IMU to landing site REFSMMAT										
		Maneuver spacecraft as required									
78:25:18	Fourth midcourse correction										
		Maneuver spacecraft as required									
81:10:00	Maneuver to TV attitude										
		Maneuver spacecraft as required									
81:55:00	Maneuver to LOI-1 burn attitude, rolled 120 deg for communications	260.4	18.9	123.7	108.6	250.0	154.7	29.8	147.1	331.7	-18 250
83:03:00	Roll - 120 deg to LOI-1 burn attitude	260.4	18.9	3.7	108.2	10.0	162.2	38.9	*	*	** **
83:11:44	Lose MSFN line of sight	260.4	18.9	3.7	*	*	148.9	18.0	*	*	** **
83:25:18	LOI-1 ignition	260.4	18.9	3.7	*	*	90.0	356.2	147.1	91.9	** **

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 1: LOI-1 Burn Cutoff to CSM/LM Undocking

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
83:31:14	LOI-1 cutoff, inertial attitude hold	58.6	-1.0	155.7	185.9	19.2	4.3	259.8	19.1	3.9	*	*	146.9	92.7	**	**
83:40:00	Maneuver to lunar surface observation attitude, inertial attitude hold	63.5	-7.8	129.2	255.6	0.0	180.0	302.2	359.8	179.8	*	*	139.4	201.4	**	**
83:44:07	Acquire MSFN line of sight	69.4	-10.4	116.7	268.2	0.0	180.0	302.2	359.8	179.8	69.8	187.3	139.4	201.4	-68	339
84:00:00	Begin orbital pitch rate for lunar surface observation, local attitude hold	105.9	-15.3	68.7	315.0	0.0	180.0	302.2	359.8	179.8	70.0	187.3	139.4	201.4	-68	339
84:26:30	Terminate orbital pitch rate, inertial attitude hold	162.8	-4.9	-3.0	315.0	0.0	180.0	231.2	0.1	179.7	140.8	191.0	145.1	335.4	-38	189
84:44:27	Enter lunar umbra	163.9	6.8	-47.2	0.4	0.0	180.0	231.2	0.1	179.7	141.2	191.1	*	*	-38	189
85:09:07	Lose MSFN line of sight	113.6	15.2	-113.7	65.7	0.0	180.0	231.2	0.1	179.7	*	*	*	*	**	**
85:29:43	Enter sunlight	66.5	7.0	-175.1	126.2	0.0	180.0	231.2	0.1	179.7	*	*	145.1	335.5	**	**
85:52:16	Acquire MSFN line of sight	68.5	-10.2	116.8	196.0	0.0	180.0	231.2	0.1	179.7	141.3	191.2	145.0	335.5	-38	189
86:52:59	Enter lunar umbra	164.0	6.8	-48.3	0.3	0.0	180.0	231.2	0.1	179.7	142.3	191.7	*	*	-36	189
86:54:00	Begin IMU realignment	163.0	7.4	-50.9	2.9	0.0	180.0	231.2	0.1	179.7	142.4	191.7	*	*	-36	189
87:15:00	Maneuver to LOI-2 burn attitude, inertial attitude hold	121.0	15.2	-107.1	58.3	359.7	0.0	231.2	359.7	359.7	142.7	11.2	*	*	37	171
87:17:20	Lose MSFN line of sight	114.8	15.3	-113.8	64.8	359.7	0.0	231.2	359.7	359.7	*	*	*	*	**	**
87:38:14	Enter sunlight	66.7	7.0	-176.2	126.1	359.6	0.0	231.2	359.7	359.7	*	*	145.1	156.0	**	**
87:44:10	LOI-2 ignition	60.2	2.4	166.0	144.4	359.6	0.0	231.2	359.7	359.7	*	*	145.1	156.0	**	**
87:44:28	LOI-2 cutoff, inertial attitude hold	60.1	2.2	165.1	145.3	359.7	0.0	231.2	359.8	359.7	*	*	145.1	155.9	**	**
88:00:00	Maneuver for communications, land-mark tracking attitude rolled 180 deg, inertial attitude hold	63.8	-9.4	119.5	230.1	0.0	180.0	269.2	359.9	179.8	*	*	165.2	248.7	**	**
88:01:20	Acquire MSFN line of sight	63.9	-10.2	115.5	234.1	0.0	180.0	269.2	359.9	179.8	104.9	187.3	165.2	248.7	-71	206
88:51:00	Begin IMU realignment	54.8	3.3	-35.5	24.0	0.0	180.0	269.2	359.9	179.8	105.8	187.5	165.2	248.9	-71	206
88:51:26	Enter lunar umbra	54.7	3.6	-36.8	25.4	0.0	180.0	269.2	359.9	179.8	105.8	187.5	*	*	-71	206
89:13:08	Lose MSFN line of sight	52.7	15.0	-103.6	91.9	0.0	180.0	269.2	359.9	179.8	*	*	*	*	**	**
89:37:11	Enter sunlight	58.3	6.7	-178.5	165.4	0.0	180.0	269.2	359.9	179.8	*	*	165.2	249.0	**	**
89:59:34	Acquire MSFN line of sight	63.7	-10.0	115.6	232.9	0.0	180.0	269.2	359.9	179.8	106.0	187.5	165.2	249.0	-71	206
90:06:00	Roll 180 deg to landmark tracking attitude, inertial attitude hold	64.1	13.3	96.1	252.2	0.0	0.0	269.2	359.9	359.8	106.1	7.5	165.2	69.1	72	154
90:41:03	Begin -0.3 deg/sec pitch rate for landmark tracking on site H-1	57.2	-3.5	-11.3	357.9	0.0	0.0	269.2	359.9	359.8	106.8	7.7	165.2	69.2	72	154
90:49:57	Enter lunar umbra	54.8	3.5	-37.6	197.7	0.0	0.0	81.9	0.1	0.2	65.8	172.0	*	*	-64	17
90:57:08	Terminate pitch rate; roll to sleep attitude, inertial attitude hold	53.4	8.8	-59.1	68.8	0.0	126.5	291.0	359.9	126.4	85.5	240.8	*	*	-29	275
91:11:40	Lose MSFN line of sight	53.0	15.0	-104.4	113.4	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
91:35:52	Enter sunlight	58.4	6.6	-179.7	187.3	0.0	126.5	291.0	359.9	126.4	*	*	149.8	261.8	**	**
91:58:03	Acquire MSFN line of sight	63.5	-10.0	114.9	254.2	0.0	126.5	291.0	359.9	126.4	85.6	240.8	149.8	261.8	-29	275
92:30:00	Begin rest period	59.9	-10.3	16.5	350.3	0.0	126.5	291.0	359.9	126.4	86.1	240.9	149.9	261.8	-29	275
92:48:33	Enter lunar umbra	54.9	3.5	-38.6	46.7	0.0	126.5	291.0	359.9	126.4	86.5	240.9	*	*	-29	275

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 1: LOI-1 Burn Cutoff to CSM/LM Undocking
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n.mi.)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	Gimbaled MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
93:09:53	Lose MSFN line of sight	53.2	15.0	-104.2	112.1	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
93:34:24	Enter sunlight	58.4	6.7	179.5	187.0	0.0	126.5	291.0	359.9	126.4	*	*	149.9	261.9	**	**
93:56:09	Acquire MSFN line of sight	63.2	-9.7	115.4	252.7	0.0	126.5	291.0	359.9	126.4	86.7	241.0	149.9	261.9	-29	275
94:47:15	Enter lunar umbra	55.0	3.6	-39.9	47.0	0.0	126.5	291.0	359.9	126.4	87.6	241.0	*	*	-29	272
95:08:13	Lose MSFN line of sight	53.4	14.9	-104.4	111.2	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
95:33:00	Enter sunlight	58.4	6.7	178.5	186.9	0.0	126.5	291.0	359.9	126.4	*	*	150.0	261.9	**	**
95:54:29	Acquire MSFN line of sight	63.0	-9.5	115.3	251.7	0.0	126.5	291.0	359.9	126.4	87.8	241.1	150.0	261.9	-29	272
96:45:50	Enter lunar umbra	55.1	3.6	-40.9	46.9	0.0	126.5	291.0	359.9	126.4	88.7	241.2	*	*	-27	272
97:06:27	Lose MSFN line of sight	53.6	14.9	-104.2	110.0	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
97:31:36	Enter sunlight	58.5	6.7	177.5	186.8	0.0	126.5	291.0	359.9	126.4	*	*	150.1	262.0	**	**
97:52:50	Acquire MSFN line of sight	62.9	-9.3	115.0	250.9	0.0	126.5	291.0	359.9	126.4	88.9	241.2	150.1	262.0	-27	272
98:44:19	Enter lunar umbra	55.2	3.6	-41.6	46.5	0.0	126.5	291.0	359.9	126.4	89.8	241.3	*	*	-27	270
99:04:42	Lose MSFN line of sight	53.8	14.8	-104.1	108.9	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
99:30:16	Enter sunlight	58.5	6.6	176.4	186.9	0.0	126.5	291.0	359.9	126.4	*	*	150.1	262.1	**	**
99:51:07	Acquire MSFN line of sight	62.6	-9.1	115.0	249.8	0.0	126.5	291.0	359.9	126.4	90.0	241.3	150.2	262.1	-27	270
100:43:02	Enter lunar umbra	55.3	3.6	-42.9	46.8	0.0	126.5	291.0	359.9	126.4	91.0	241.4	*	*	-27	270
101:00:00	End rest period	53.8	13.9	-94.7	98.7	0.0	126.5	291.0	359.9	126.4	91.2	241.4	*	*	**	**
101:03:13	Lose MSFN line of sight	54.0	14.8	-104.9	108.6	0.0	126.5	291.0	359.9	126.4	*	*	*	*	**	**
101:28:49	Enter sunlight	58.6	6.7	175.5	186.6	0.0	126.5	291.0	359.9	126.4	*	*	150.2	262.1	**	**
101:49:14	Acquire MSFN line of sight	62.4	-8.6	115.4	248.3	0.0	126.5	291.0	359.9	126.4	91.1	241.4	150.2	262.1	-27	268
102:41:33	Enter lunar umbra	55.4	3.6	-43.7	46.5	0.0	126.5	291.0	359.9	126.4	92.1	241.5	*	*	-27	268
102:50:00	Maneuver for LM steerable antenna communications, landmark tracking attitude rolled -120 deg. inertial attitude hold	54.3	9.7	-69.1	51.6	0.0	240.0	270.4	0.0	239.9	112.6	128.6	*	*	-35	117
103:00:00	Begin IMU realignment	54.1	14.4	-100.1	82.3	0.0	240.0	270.4	0.0	239.9	112.7	128.6	*	*	-35	117
103:01:25	Lose MSFN line of sight	54.2	14.7	-104.6	86.6	0.0	240.0	270.4	0.0	239.9	*	*	*	*	**	**
103:27:31	Enter sunlight	58.6	6.6	174.3	166.2	0.0	240.0	270.4	0.0	239.9	*	*	165.0	187.1	**	**
103:47:29	Acquire MSFN line of sight	62.2	-8.6	115.5	226.5	0.0	240.0	270.4	0.0	239.9	112.6	128.6	165.0	187.1	-35	117
104:40:14	Enter lunar umbra	55.6	3.7	-45.0	26.0	0.0	240.0	270.4	0.0	239.9	113.6	128.8	*	*	-35	117
104:59:54	Lose MSFN line of sight	54.3	14.7	-105.2	86.2	0.0	240.0	270.4	0.0	239.9	*	*	*	*	**	**
105:26:02	Enter sunlight	58.6	6.7	173.5	165.8	0.0	240.0	270.4	0.0	239.9	*	*	165.0	187.4	**	**
105:45:55	Acquire MSFN line of sight	62.0	-8.5	115.0	225.9	0.0	240.0	270.4	0.0	239.9	113.7	128.8	165.0	187.4	-35	117
105:46:00	Deploy LM landing gear	62.0	-8.5	114.8	226.2	0.0	240.0	270.4	0.0	239.9	113.7	128.8	165.0	187.4	-35	117
106:10:00	Roll 120 deg to landmark tracking attitude, inertial attitude hold	61.2	-14.7	40.7	298.5	0.0	0.0	270.4	0.0	359.9	114.1	8.9	165.0	67.5	65	163
106:29:37	Begin -0.3 deg/sec pitch rate for landmark tracking on site 193	57.3	-3.7	-18.8	357.9	0.0	0.0	270.4	0.0	359.9	114.5	9.0	165.0	67.5	65	163

* No line of sight
** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 1: LOI-1 Burn Cutoff to CSM/LM Undocking
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
106:31:59	Terminate pitch rate; maneuver to AGS calibration attitude, inertial attitude hold	56.3	0.6	-34.6	261.4	22.4	7.5	157.5	22.5	7.5	124.1	144.8	69.3	165.6	-41	139
106:38:48	Enter lunar umbra	55.7	3.6	-45.9	273.0	22.4	7.5	157.5	22.5	7.5	124.0	144.8	*	*	-41	139
106:57:50	Lose MSFN line of sight	54.5	14.6	-104.1	331.2	22.4	7.5	157.5	22.5	7.5	*	*	*	*	**	**
107:24:37	Enter sunlight	58.6	6.7	172.6	52.8	22.5	7.5	157.5	22.5	7.5	*	*	69.2	165.7	**	**
107:40:00	Maneuver to undocking attitude, inertial attitude hold	61.4	-5.3	127.4	226.7	0.0	180.0	284.9	0.0	180.0	*	*	155.6	215.3	**	**
107:44:16	Acquire MSFN line of sight	61.8	-8.3	114.8	239.6	0.0	180.0	284.9	0.0	180.0	100.5	188.3	155.6	215.3	-76	218

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 2: CSM/LM Undocking to LM Landing

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			CSM Local Horizontal Attitude/ LM FDI Attitudes			IMU Gimbal Angles			Look Angles to Earth		Look Angles Other Vehicle		CSM HGA Pointing Angles/LM S-band Pointing Angles		
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OCA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)	
107:54:22	CSM/LM soft undocking, inertial attitude hold	CSM LM	62.2 62.2	-13.7 -13.7	84.1 84.1	270.0 284.9	0.0 300.0	180.0 180.0	0.0 0.0	284.9 104.9	0.0 0.0	180.0 120.0	100.6 79.4	188.4 51.6	0.0 0.0	0.0 0.0	-76 132	218 25
107:55:42	LM maneuver to an eye-to-eye attitude, inertial attitude hold	LM	62.2	-14.1	80.0	194.0	0.0	180.0	0.0	14.0	0.0	180.0	14.1	215.6	97.0	180.0	71	-52
108:24:22	CSM separation burn ignition, inertial attitude hold; LM maneuver to monitor the CSM after the burn, inertial attitude hold	CSM LM	58.1 58.1	-6.6 -6.6	-8.4 -8.4	0.0 247.0	0.0 0.0	180.0 180.0	0.0 67.0	284.9 0.0	0.0 180.0	180.0 41.5	188.5 347.5	36.0 2.0	0.0 180.0	0.0 147	-76 -39	218 -39
108:31:00	CSM begin SXT tracking - VHF ranging, line-of-sight maintenance	CSM	56.7	-1.5	-28.0	67.0	0.0	180.0	0.0	331.0	0.0	180.0	55.7	190.0	35.0	180.0	**	**
108:36:00	CSM terminate automatic tracking, inertial attitude hold; LM begin RR tracking, manual line-of-sight maintenance	CSM LM	55.7 56.0	2.5 2.5	-42.8 -42.8	84.1 278.0	0.0 0.0	180.0 180.0	0.0 98.0	333.0 0.0	0.0 180.0	53.9 71.8	190.0 351.3	35.0 90.0	180.0 180.0	-52 **	347 **	
108:37:13	CSM enter lunar umbra, LM enter lunar umbra	CSM LM	55.5 55.8	3.4 3.4	-46.4 -46.3	87.8 277.2	0.0 0.0	180.0 180.0	0.0 97.2	333.0 0.0	0.0 180.0	53.9 71.0	190.0 351.3	33.3 90.0	180.0 180.0	-52 **	347 **	
108:44:00	CSM and LM maneuver to IMU realignment attitude, inertial attitude hold	CSM LM	54.6 55.0	8.5 8.5	-66.7 -66.6	108.6 332.0	0.0 27.0	0.0 347.0	0.0 348.0	333.0 0.0	0.0 332.0	54.0 63.5	10.1 43.6	28.5 142.8	0.0 224.2	0.0 131	** 7	** 7
108:45:00	LM begin IMU realignment	LM	54.9	8.9	-69.6	332.0	27.0	347.0	326.0	348.0	332.0	36.5	43.6	144.1	244.2	131	7	
108:50:00	CSM begin IMU realignment	CSM	54.3	12.0	-85.1	126.9	0.0	0.0	333.0	0.0	0.0	54.0	10.1	20.1	0.0	0.0	**	**
108:55:46	CSM and LM lose MSFN line of sight	CSM LM	54.3 54.8	14.1 14.1	-103.1 -103.0	144.4 332.0	0.0 27.0	0.0 347.0	0.0 348.0	333.0 0.0	0.0 332.0	*	*	10.4 158.7	0.0 244.2	** **	** **	** **
109:06:00	LM maneuver to DOI burn attitude, inertial attitude hold	LM	55.7	14.9	-137.0	299.2	0.0	0.0	299.2	0.0	0.0	*	*	157.0	180.0	**	**	
109:10:00	CSM begin SXT tracking - VHF ranging, line-of-sight maintenance	CSM	55.9	13.9	-148.9	204.8	0.0	0.0	349.0	0.0	0.0	*	*	35.0	180.0	**	**	
109:23:00	LM DOI burn ignition: CSM, line-of-sight maintenance; LM, inertial attitude hold	CSM LM	58.6 58.6	6.8 6.9	172.1 172.2	215.3 299.2	0.0 0.0	0.0 0.0	320.7 299.2	0.0 0.0	0.0 0.0	*	*	35.0 166.0	180.0 0.0	** **	** **	** **
109:23:13	CSM and LM enter sunlight	CSM LM	58.6 58.6	6.7 6.7	171.5 171.7	215.6 299.2	0.0 0.0	0.0 0.0	320.3 299.2	0.0 0.0	0.0 0.0	*	*	35.0 165.2	180.0 0.0	** **	** **	** **
109:23:28	LM DOI burn cutoff: CSM, line-of-sight maintenance; LM, inertial attitude hold	CSM LM	58.7 58.6	6.5 6.5	170.8 170.9	216.7 299.2	0.0 0.0	0.0 0.0	320.6 299.2	0.0 0.0	0.0 0.0	*	*	35.0 165.4	180.0 0.0	** **	** **	** **
109:25:00	CSM terminate SXT tracking, inertial attitude hold; LM begin RR tracking, manual line-of-sight maintenance	CSM LM	59.0 58.6	5.3 5.4	166.2 166.4	224.4 198.7	0.0 0.0	0.0 0.0	323.7 198.7	0.0 0.0	0.0 0.0	*	*	35.0 90.0	180.0 180.0	** **	** **	** **
109:26:00	CSM begin SXT tracking - VHF ranging, line-of-sight maintenance	CSM	59.3	4.6	163.3	228.6	0.0	0.0	324.8	0.0	0.0	*	*	35.0	180.0	**	**	
109:32:00	LM terminate RR tracking, inertial attitude hold	LM	56.0	0.0	146.0	204.4	0.0	0.0	204.4	0.0	0.0	*	*	90.0	180.0	**	**	
109:38:00	LM maneuver to PDI attitude, inertial attitude hold	LM	51.0	-4.8	128.4	109.3	0.0	0.0	109.3	0.0	0.0	*	*	11.9	0.0	**	**	
109:41:59	CSM acquire MSFN line of sight, 80-deg roll, inertial attitude hold	CSM	62.0	-7.7	116.3	293.4	0.0	80.0	341.3	0.0	80.0	45.9	291.5	35.0	100.0	16	316	
109:42:33	LM acquire MSFN line of sight	LM	46.5	-8.1	114.8	109.3	0.0	0.0	109.3	0.0	0.0	82.7	171.7	17.5	0.0	12	0	
109:47:00	CSM reverse 80-deg roll, inertial attitude hold	CSM	62.4	-10.9	101.3	308.4	0.0	0.0	341.3	0.0	0.0	45.9	11.6	30.3	180.0	**	**	

* No line of sight
** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 2: CSM/LM Undocking to LM Landing
(Continued)

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			CSM Local Horizontal Attitude/ LM FDAL Angles			IMU Gimbal Angles			Look Angles to Earth		Look Angles Other Vehicle		CSM HGA Pointing Angles/LM S-band Pointing Angles	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OCA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
109:50:00	CSM begin SXT tracking - VHF ranging, line-of-sight maintenance	CSM	62.5	-12.5	92.2	323.3	0.0	0.0	347.1	0.0	0.0	40.2	12.9	35.0	180.0	**	**
110:12:00	CSM terminate automatic tracking, begin manual SXT tracking, line-of-sight maintenance	CSM	60.4	-13.1	23.8	2.8	0.0	0.0	320.3	0.0	0.0	67.0	9.1	35.0	180.0	**	**
110:20:00	LM PDI burn ignition	CSM LM	58.7 8.1	-8.7 -6.9	-0.5 -8.0	9.3 109.3	0.0 0.0	0.0 0.0	302.6 109.3	0.0 0.0	0.0 0.0	84.7 82.1	8.4 171.6	35.0 21.7	180.0 180.0	** 12	** 0
110:31:19	LM landing	CSM LM	56.4 0.0	0.0 -3.0	-34.1 -23.4	237.7 0.0	0.0 0.0	0.0 0.0	136.6 0.0	0.0 0.0	0.0 0.0	108.9 27.2	171.0 18.0	35.0 79.8	180.0 180.0	** 121	** -32

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 3: LM Landing to LM Lift-off (CSM Solo Operations)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
110:31:19	LM landing	56.4	-0.1	-34.1	237.7	0.0	0.0	136.6	0.0	0.0	108.9	171.2	53.2	162.7	-69	156
110:35:49	CSM enter lunar umbra	55.6	3.5	-47.4	251.4	0.0	0.0	136.6	0.0	0.0	108.8	171.2	*	*	-69	156
110:40:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	55.1	6.7	-59.9	207.0	0.0	0.0	79.4	0.0	0.0	52.2	169.4	*	*	-51	13
110:46:00	CSM begin IMU realignment	54.5	10.7	-78.0	225.3	0.0	0.0	79.4	0.0	0.0	52.2	169.4	*	*	-51	13
110:54:03	CSM lose MSFN line of sight	54.5	14.3	-103.1	250.0	0.0	0.0	79.4	0.0	0.0	*	*	*	*	**	**
111:21:49	CSM enter sunlight	58.7	6.7	170.5	334.6	0.0	0.0	79.4	0.0	0.0	*	*	14.8	69.3	**	**
111:40:16	CSM acquire MSFN line of sight	61.8	-7.5	116.3	30.4	0.0	0.0	79.4	0.0	0.0	52.2	169.4	14.8	69.2	-51	13
112:00:00	CSM maneuver to landmark tracking attitude, local attitude hold	61.8	-15.3	55.8	338.0	0.0	0.0	327.6	0.0	0.0	60.7	9.7	116.3	15.4	58	18
112:31:33	CSM terminate local attitude hold; roll 180 deg to communications attitude, inertial attitude hold	56.2	1.2	-39.9	338.0	0.0	180.0	232.0	0.0	180.0	155.3	200.6	144.7	335.6	-23	189
112:34:25	CSM enter lunar umbra	55.8	3.5	-48.4	346.7	0.0	180.0	232.0	0.0	180.0	155.3	200.6	*	*	-23	189
112:52:22	CSM lose MSFN line of sight	54.7	14.2	-103.2	41.6	0.0	180.0	232.0	0.0	180.0	*	*	*	*	**	**
113:20:26	CSM enter sunlight	58.7	6.7	169.5	127.1	0.0	180.0	232.0	0.0	180.0	*	*	144.7	335.6	**	**
113:38:34	CSM acquire MSFN line of sight	61.6	-7.3	116.2	182.0	0.0	180.0	232.0	0.0	180.0	155.4	200.7	144.7	335.6	-23	189
114:00:00	CSM maneuver to landmark tracking attitude, local attitude hold	61.4	-15.3	50.4	0.0	0.0	0.0	345.4	0.0	0.0	44.3	12.2	99.1	14.0	43	11
114:33:01	CSM enter lunar umbra	55.9	3.5	-49.4	0.0	0.0	0.0	245.3	0.0	0.0	143.6	14.5	*	*	35	170
114:37:00	CSM terminate local attitude hold; roll 180 deg to communications attitude, inertial attitude hold	55.4	6.6	-61.3	0.0	0.0	180.0	233.1	0.0	180.0	155.3	200.8	*	*	-23	190
114:50:45	CSM lose MSFN line of sight	54.9	14.2	-103.5	42.0	0.0	180.0	233.1	0.0	180.0	*	*	*	*	**	**
115:19:03	CSM enter sunlight	58.7	6.7	168.5	128.2	0.0	180.0	233.1	0.0	180.0	*	*	145.7	335.0	**	**
115:36:58	CSM acquire MSFN line of sight	61.4	-7.2	115.6	182.4	0.0	180.0	233.1	0.0	180.0	155.3	200.9	145.7	335.0	-23	190
116:31:38	CSM enter lunar umbra	56.0	3.6	-50.5	347.8	0.0	180.0	233.1	0.0	180.0	156.2	201.9	*	*	-23	190
116:49:07	CSM lose MSFN line of sight	55.1	14.1	-103.8	41.2	0.0	180.0	233.1	0.0	180.0	*	*	*	*	**	**
117:17:38	CSM enter sunlight	58.7	6.7	167.5	128.1	0.0	180.0	233.1	0.0	180.0	*	*	145.6	335.0	**	**
117:35:23	CSM acquire MSFN line of sight	61.2	-7.0	115.4	181.8	0.0	180.0	233.1	0.0	180.0	156.3	202.0	145.6	335.0	-23	190
118:22:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	57.3	-3.0	-27.2	322.7	45.0	179.9	233.1	45.0	180.1	123.0	242.7	114.5	304.3	-22	234
118:30:00	CSM begin IMU realignment***	56.1	3.4	-50.8	347.1	45.0	179.9	330.7	29.4	48.8	123.0	244.9	114.5	304.3	-21	234
118:30:13	CSM enter lunar umbra	56.1	3.6	-51.5	347.8	45.0	179.9	330.7	29.4	48.8	123.0	244.9	*	*	-21	234
118:47:21	CSM lose MSFN line of sight	55.3	14.0	-103.6	40.1	45.0	179.9	330.7	29.4	48.8	*	*	*	*	**	**
119:10:00	CSM maneuver to plane change 1 burn attitude, inertial attitude hold	57.7	10.8	-174.7	109.5	85.5	138.6	0.0	0.0	0.0	*	*	*	*	**	**
119:16:15	CSM enter sunlight	58.7	6.7	166.5	128.5	85.5	138.6	0.0	0.0	0.0	*	*	80.0	342.4	**	**
119:33:21	CSM acquire MSFN line of sight	61.0	-6.6	116.2	180.3	85.5	138.5	0.0	0.0	0.0	85.4	290.1	80.0	342.4	20	276
119:47:02	CSM plane change 1 burn	61.4	-14.1	74.8	221.6	85.5	138.5	0.0	0.0	0.0	85.4	290.3	80.0	342.4	20	276
120:10:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	59.0	-6.9	4.2	339.4	0.0	128.3	273.0	0.0	39.0	110.4	237.0	158.2	267.9	-30	245

* No line of sight

** No HGA line of sight

*** Gimbal angles reflect change in REFSMMAT.

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 3: LM Landing to LM Lift-off (CSM Solo Operations)
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local Horizontal Attitude			IMU Gimbal Angles		Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
120:29:05	CSM enter lunar umbra	56.2	6.9	-52.5	37.4	0.0	128.3	273.0	0.0	110.8	237.1	*	*	-30	245
120:30:00	CSM begin IMU realignment**	56.1	7.5	-55.3	40.2	0.0	128.3	265.3	359.9	128.1	237.1	*	*	-30	245
120:45:28	CSM lose MSFN line of sight	55.5	14.0	-103.1	87.4	0.0	128.3	265.3	359.9	128.1	*	*	*	**	**
121:00:00	CSM maneuver to rest attitude, inertial attitude hold	56.6	11.9	-148.7	144.2	0.0	121.1	277.8	359.9	120.9	*	*	*	**	**
121:15:11	CSM enter sunlight	58.8	2.6	165.5	190.3	0.0	121.1	277.8	359.9	120.9	*	147.4	263.0	**	**
121:31:47	CSM acquire MSFN line of sight	60.8	-9.1	116.3	240.5	0.0	121.1	277.8	359.9	120.9	98.5	147.4	263.0	-25	261
122:27:41	CSM enter lunar umbra	56.4	6.9	-53.5	49.8	0.0	121.1	277.8	359.9	120.9	99.5	244.2	*	-25	260
122:43:48	CSM lose MSFN line of sight	55.7	14.0	-103.2	98.9	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
123:13:48	CSM enter sunlight	58.7	2.6	164.5	190.3	0.0	121.0	277.8	359.9	120.9	*	147.5	263.1	**	**
123:30:06	CSM acquire MSFN line of sight	60.6	-8.9	116.2	239.6	0.0	121.0	277.8	359.9	120.9	99.6	147.5	263.1	-25	259
124:26:18	CSM enter lunar umbra	56.5	6.9	-54.6	49.8	0.0	121.0	277.8	359.9	120.9	100.6	244.3	*	-25	258
124:42:09	CSM lose MSFN line of sight	55.9	14.0	-103.4	98.1	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
125:12:24	CSM enter sunlight	58.7	2.6	163.5	190.2	0.0	121.0	277.8	359.9	120.9	*	147.5	263.1	**	**
125:28:24	CSM acquire MSFN line of sight	60.4	-8.7	116.1	238.6	0.0	121.0	277.8	359.9	120.9	100.7	147.6	263.1	-25	258
126:24:53	CSM enter lunar umbra	56.7	6.9	-55.6	49.7	0.0	121.0	277.8	359.9	120.9	101.7	244.4	*	-24	257
126:40:28	CSM lose MSFN line of sight	56.1	13.9	-103.6	97.1	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
127:11:01	CSM enter sunlight	58.7	2.6	162.5	190.1	0.0	121.0	277.8	359.9	120.9	*	147.6	263.2	**	**
127:26:43	CSM acquire MSFN line of sight	60.2	-8.6	116.0	237.6	0.0	121.0	277.8	359.9	120.9	101.8	147.6	263.2	-24	257
128:23:30	CSM enter lunar umbra	56.9	6.9	-56.7	49.7	0.0	121.0	277.8	359.9	120.9	102.8	244.6	*	-24	256
128:38:46	CSM lose MSFN line of sight	56.3	13.9	-103.6	96.2	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
129:09:37	CSM enter sunlight	58.7	2.6	161.5	190.0	0.0	121.0	277.8	359.9	120.9	*	147.7	263.2	**	**
129:24:57	CSM acquire MSFN line of sight	60.0	-8.4	116.1	236.4	0.0	121.0	277.8	359.9	120.9	102.9	147.7	263.3	-24	256
130:22:06	CSM enter lunar umbra	57.0	6.9	-57.7	49.6	0.0	121.0	277.8	359.9	120.9	103.9	244.7	*	-24	254
130:36:58	CSM lose MSFN line of sight	56.6	13.8	-103.4	94.9	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
131:08:14	CSM enter sunlight	58.7	2.6	160.5	189.9	0.0	121.0	277.8	359.9	120.9	*	147.8	263.3	**	**
131:23:16	CSM acquire MSFN line of sight	59.8	-8.2	116.0	235.5	0.0	121.0	277.8	359.9	120.9	104.0	147.8	263.3	-24	254
132:20:42	CSM enter lunar umbra	57.2	6.9	-58.7	49.5	0.0	121.0	277.8	359.9	120.9	105.0	244.9	*	-23	253
132:35:19	CSM lose MSFN line of sight	56.8	13.7	-103.6	94.0	0.0	121.0	277.8	359.9	120.9	*	*	*	**	**
133:06:51	CSM enter sunlight	58.7	2.6	159.4	189.9	0.0	120.9	277.8	359.9	120.9	*	147.9	263.4	**	**
133:21:20	CSM acquire MSFN line of sight	59.6	-7.9	116.6	233.8	0.0	120.9	277.8	359.9	120.9	105.0	147.9	263.4	-23	253
134:00:00	CSM maneuver to landmark tracking attitude (site Lansberg A), local attitude hold	58.7	-7.0	-2.4	338.0	0.0	0.0	265.0	0.0	359.9	118.5	159.0	37.7	**	**
134:11:00	CSM terminate local attitude hold; roll 180 deg for communications, inertial attitude hold	57.9	1.0	-35.0	338.0	0.0	180.0	231.6	0.0	179.9	192.1	159.3	321.6	-26	186
134:19:19	CSM enter lunar umbra	57.4	6.9	-59.8	3.3	0.0	180.0	231.6	0.0	179.9	192.2	*	*	-26	186
134:33:24	CSM lose MSFN line of sight	57.0	13.6	-103.0	46.1	0.0	180.0	231.6	0.0	179.9	*	*	*	**	**
135:05:26	CSM enter sunlight	58.6	2.6	158.5	143.5	0.0	180.0	231.6	0.0	179.9	*	159.3	321.6	**	**

* No line of sight

** No HGA line of sight

*** Gimbal angles reflect change in REFSMAT.

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 3: LM Landing to LM Lift-off (CSM Solo Operations)
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	Gimbaled (deg)	MGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
135:06:00	CSM maneuver to SJ58 photography attitude, local attitude hold	58.6	2.2	156.8	213.0	0.0	0.0	299.3	359.9	0.0	*	*	127.6	16.1	**	**
135:19:40	CSM acquire MSFN line of sight	59.4	-7.7	116.4	213.0	0.0	0.0	257.9	0.0	359.9	125.9	7.1	164.0	52.8	**	**
136:17:54	CSM enter lunar umbra	57.5	6.9	-60.7	213.0	0.0	0.0	81.4	0.0	0.1	56.5	173.0	*	*	-54	11
136:31:40	CSM lose MSFN line of sight	57.2	13.5	-102.9	213.0	0.0	0.0	39.5	0.0	0.1	*	*	*	*	**	**
137:04:03	CSM enter sunlight	58.6	2.6	157.5	213.0	0.0	0.0	301.1	0.0	0.0	*	*	126.0	15.8	**	**
137:18:00	CSM acquire MSFN line of sight	59.2	-7.5	116.2	213.0	0.0	0.0	258.8	0.0	359.9	126.1	7.2	163.5	50.6	**	**
137:45:00	CSM terminate local attitude hold; maneuver to photograph Theophilus, inertial attitude hold	59.1	-13.1	32.7	264.0	334.0	90.0	228.0	334.0	90.0	150.5	230.8	156.8	121.2	-18	204
137:50:00	CSM maneuver to photograph Descartes, inertial attitude hold	59.0	-11.1	17.3	268.1	329.0	90.0	217.0	329.0	90.0	152.7	205.4	145.9	115.6	-24	193
138:00:00	CSM maneuver to photograph Fra Mauro, inertial attitude hold	58.4	-5.1	-12.9	262.5	307.0	86.0	181.0	307.0	86.0	128.7	151.7	113.8	104.7	-43	149
138:06:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	58.1	-0.7	-30.6	49.6	0.0	180.0	310.0	0.0	180.0	76.0	186.1	117.5	194.3	-74	337
138:16:31	CSM enter lunar umbra	57.7	7.0	-61.8	81.6	0.0	180.0	310.0	0.0	180.0	76.2	186.1	*	*	-74	337
138:17:00	CSM begin IMU realignment	57.7	7.3	-63.2	83.1	0.0	180.0	310.0	0.0	180.0	76.2	186.1	*	*	-74	337
138:30:01	CSM lose MSFN line of sight	57.4	13.5	-103.2	122.6	0.0	180.0	310.0	0.0	180.0	*	*	*	*	**	**
139:02:40	CSM enter sunlight	58.5	2.6	156.5	221.8	0.0	180.0	310.0	0.0	180.0	*	*	117.5	194.3	**	**
139:16:19	CSM acquire MSFN line of sight	59.1	-7.3	116.1	263.2	0.0	180.0	310.0	0.0	180.0	76.3	186.1	117.5	194.3	-74	337
139:41:00	CSM roll 180 deg to landmark tracking attitude (site 193), local attitude hold	59.1	-13.8	39.8	338.0	0.0	0.0	310.0	0.0	0.0	76.6	6.1	117.5	14.3	**	**
140:06:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	58.1	0.4	-35.8	55.7	0.0	180.0	311.9	0.0	180.0	75.3	186.2	115.7	194.1	-73	339
140:15:07	CSM enter lunar umbra	57.8	7.0	-62.8	83.4	0.0	180.0	311.9	0.0	180.0	75.5	186.2	*	*	-73	339
140:16:00	CSM begin IMU realignment	57.8	7.5	-65.5	86.1	0.0	180.0	311.9	0.0	180.0	75.5	186.2	*	*	-73	339
140:28:24	CSM lose MSFN line of sight	57.7	13.4	-103.5	123.8	0.0	180.0	311.9	0.0	180.0	*	*	*	*	**	**
141:01:16	CSM enter sunlight	58.5	2.6	155.5	223.6	0.0	180.0	311.9	0.0	180.0	*	*	115.8	194.1	**	**
141:14:45	CSM acquire MSFN line of sight	58.9	-7.2	115.6	264.5	0.0	180.0	311.9	0.0	180.0	75.5	186.2	115.8	194.1	-73	339
141:21:00	CSM roll 180 deg to LM tracking attitude, inertial attitude hold	59.0	-10.9	96.7	283.4	0.0	0.0	311.9	0.0	0.0	75.5	6.2	115.8	14.1	**	**
141:39:00	CSM terminate inertial attitude hold; begin local attitude hold	58.9	-13.9	40.6	338.0	0.0	0.0	311.9	0.0	0.0	75.8	6.2	115.8	14.1	**	**
141:59:19	CSM terminate local attitude hold; begin manual line-of-sight maintenance to LM	58.4	-3.5	-21.2	338.0	0.0	0.0	250.3	0.0	0.0	137.5	9.0	167.2	81.7	**	**

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 4: LM Lift-off to CSM/LM Docking

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position				CSM Local				IMU			Look Angles to Earth		Look Angles Other Vehicle		CSM HGA Pointing Angles/LM S-band Pointing Angles	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	ICA (deg)	MCA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)	Pitch (deg)	Yaw (deg)
142:01:18	LM lift-off (ascent burn ignition)	CSM	58.3	-2.1	-27.0	260.0	0.0	0.0	166.3	0.0	0.0	137.8	171.0	35.0	180.0	-40	171	-40	171
142:01:18	LM lift-off (ascent burn ignition)	LM	-1.3	-3.0	-23.4	0.0	0.0	0.0	0.0	0.0	0.0	28.7	12.7	45.1	180.0	124	-33	124	-33
142:08:28	Insertion burn cutoff, LM inertial attitude hold	CSM	58.1	3.3	-48.2	233.3	0.0	0.0	117.8	0.0	0.0	89.6	174.0	35.0	180.0	-83	90	-83	90
142:08:28	Insertion burn cutoff, LM inertial attitude hold	LM	8.6	-0.5	-33.2	257.4	20.3	359.6	257.3	359.6	339.7	130.7	27.9	5.6	24.5	197	45	197	45
142:13:28	CSM and LM begin IMU realignment	CSM	58.0	6.8	-63.1	217.7	0.0	0.0	87.0	0.0	0.0	58.9	172.9	19.6	180.0	-56	13	-56	13
142:13:28	CSM and LM begin IMU realignment	LM	10.9	3.5	-49.2	317.5	29.9	342.5	308.6	344.9	328.9	81.8	39.7	62.3	202.9	144	20	144	20
142:13:50	CSM enter umbra	CSM	58.0	7.0	-64.2	219.0	0.0	0.0	87.0	0.0	0.0	58.9	172.9	21.2	180.0	-56	13	-56	13
142:14:50	LM enter umbra	LM	11.8	4.6	-53.6	317.5	29.9	342.5	308.6	344.9	328.9	81.8	39.7	66.7	204.0	144	20	144	20
142:16:28	CSM complete IMU realignment, begin VHF ranging	CSM	57.9	9.9	-78.2	232.6	0.0	0.0	87.0	0.0	0.0	58.9	172.9	35.0	180.0	-56	13	-56	13
142:16:28	CSM complete IMU realignment, begin VHF ranging	LM	14.4	7.3	-65.3	317.5	29.9	342.5	308.6	344.9	328.9	81.8	39.7	77.3	207.6	144	20	144	20
142:23:28	LM complete IMU realignment, begin RR tracking	CSM	57.9	12.3	-93.5	231.8	0.0	0.0	70.7	0.0	0.0	42.6	171.0	35.0	180.0	-40	9	-40	9
142:23:28	LM complete IMU realignment, begin RR tracking	LM	18.8	10.5	-81.5	305.7	0.0	0.0	305.7	0.0	0.0	82.7	6.1	90.0	180.0	170	0	170	0
142:26:48	CSM lose MSFN line of sight	CSM	57.9	13.4	-103.9	231.1	0.0	0.0	59.4	0.0	0.0	*	*	35.0	180.0	**	**	**	**
142:27:52	LM lose MSFN line of sight	LM	23.0	12.5	-95.8	291.1	0.0	0.0	291.1	0.0	0.0	*	*	90.0	180.0	**	**	**	**
142:50:00	CSM maneuver to MI CSI burn attitude, inertial attitude hold	CSM	58.2	9.2	-176.0	155.5	0.0	0.0	273.8	0.0	0.0	*	*	35.2	0.0	**	**	**	**
142:50:00	CSM maneuver to MI CSI burn attitude, inertial attitude hold	LM	41.5	10.8	-167.2	219.0	0.0	0.0	219.0	0.0	0.0	*	*	90.0	180.0	**	**	**	**
142:58:05	CSI burn ignition	CSM	58.4	3.9	159.8	180.0	0.0	0.0	273.8	0.0	0.0	*	*	10.0	0.0	**	**	**	**
142:58:05	CSI burn ignition	LM	43.5	5.9	168.0	191.1	0.0	0.0	191.1	0.0	0.0	*	*	87.2	180.0	**	**	**	**
142:58:50	CSI burn cutoff	CSM	58.4	3.3	157.5	182.3	0.0	0.0	273.8	0.0	0.0	*	*	7.7	0.0	**	**	**	**
142:58:50	CSI burn cutoff	LM	43.5	5.3	165.8	191.1	0.0	0.0	191.1	0.0	0.0	*	*	89.6	180.0	**	**	**	**
142:59:52	CSM enter sunlight	CSM	58.5	2.6	154.5	185.3	0.0	0.0	273.8	0.0	0.0	*	*	4.7	0.0	**	**	**	**
143:03:25	LM enter sunlight	LM	43.6	1.9	151.9	177.9	0.0	0.0	177.9	0.0	0.0	*	*	90.0	180.0	**	**	**	**
143:04:50	CSM and LM begin VHF ranging, and RR tracking, respectively	CSM	58.6	-1.2	139.8	225.1	0.0	0.0	298.4	0.0	0.0	*	*	35.0	180.0	**	**	**	**
143:04:50	CSM and LM begin VHF ranging, and RR tracking, respectively	LM	43.7	0.8	147.6	173.4	0.0	0.0	173.4	0.0	0.0	*	*	90.0	180.0	**	**	**	**
143:13:05	CSM acquire MSFN line of sight	CSM	58.7	-7.1	115.4	225.3	0.0	0.0	274.3	0.0	0.0	113.9	6.6	35.0	180.0	**	**	**	**
143:16:20	LM acquire MSFN line of sight	LM	43.8	-7.6	112.7	138.8	0.0	0.0	138.8	0.0	0.0	110.3	173.5	90.0	180.0	-10	19	-10	19
143:50:50	CSM and LM and VHF ranging and RR tracking, respectively	CSM	58.5	-8.3	-1.1	227.6	0.0	0.0	161.4	0.0	0.0	132.1	171.7	35.0	180.0	-46	171	-46	171
143:50:50	CSM and LM and VHF ranging and RR tracking, respectively	LM	43.5	-9.3	3.7	36.4	0.0	0.0	36.4	0.0	0.0	9.6	140.3	90.0	180.0	81	-38	81	-38
144:01:50	CSM and LM begin VHF ranging and RR tracking, respectively	CSM	58.3	-0.6	-33.8	229.1	0.0	0.0	129.5	0.0	0.0	100.2	173.8	35.0	180.0	-77	149	-77	149
144:01:50	CSM and LM begin VHF ranging and RR tracking, respectively	LM	43.4	-1.6	-29.9	4.5	0.0	0.0	4.5	0.0	0.0	25.4	14.5	90.0	180.0	120	-34	120	-34
144:12:31	CSM enter umbra	CSM	58.2	7.1	-65.5	231.3	0.0	0.0	99.8	0.0	0.0	70.5	173.5	35.0	180.0	-68	16	-68	16
144:12:43	LM enter umbra	LM	43.2	6.5	-62.9	333.4	0.0	0.0	333.4	0.0	0.0	56.3	7.4	90.0	180.0	150	-18	150	-18
144:24:46	LM lose MSFN line of sight	LM	43.2	13.0	-100.4	301.1	0.0	0.0	301.1	0.0	0.0	*	*	90.0	180.0	**	**	**	**
144:24:46	LM lose MSFN line of sight	CSM	58.1	13.2	-103.2	235.6	0.0	0.0	66.1	0.0	0.0	*	*	35.0	180.0	**	**	**	**
144:24:53	CSM lose MSFN line of sight	CSM	58.1	14.3	-121.9	191.3	0.0	0.0	3.6	0.0	0.0	*	*	12.6	0.0	**	**	**	**
144:30:50	CSM maneuver to MI TPI burn attitude, inertial attitude hold	LM	43.3	14.3	-119.8	286.2	0.0	0.0	286.2	0.0	0.0	*	*	90.0	180.0	**	**	**	**
144:36:50	TPI burn ignition	CSM	58.1	13.9	-140.7	209.5	0.0	0.0	3.6	0.0	0.0	*	*	0.0	0.0	**	**	**	**
144:36:50	TPI burn ignition	LM	43.3	14.0	-139.1	273.4	0.0	0.0	273.4	0.0	0.0	*	*	90.6	180.0	**	**	**	**
144:37:13	TPI burn cutoff	CSM	58.1	13.9	-141.9	210.6	0.0	0.0	3.6	0.0	0.0	*	*	1.6	179.5	**	**	**	**
144:37:13	TPI burn cutoff	LM	43.4	14.0	-140.3	274.7	0.0	0.0	274.7	0.0	0.0	*	*	92.7	180.0	**	**	**	**
144:58:33	CSM enter sunlight	CSM	58.4	2.5	153.3	277.8	0.0	0.0	5.3	0.0	0.0	*	*	35.0	180.0	**	**	**	**
144:58:33	CSM enter sunlight	LM	50.6	2.2	152.2	240.3	0.0	0.0	240.3	0.0	0.0	*	*	90.0	180.0	**	**	**	**
144:58:59	LM enter sunlight	LM	50.6	2.2	152.2	240.3	0.0	0.0	240.3	0.0	0.0	25.0	15.0	35.0	180.0	**	**	**	**
145:11:25	CSM acquire MSFN line of sight	CSM	58.5	-6.9	115.2	315.6	0.0	0.0	5.2	0.0	0.0	*	*	15.0	180.0	**	**	**	**

* No line of sight

** No HGA/LM S-band steerable line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 4: LM Lift-off to CSM/LM Docking
(Continued)

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			CSM Local Horizontal Attitude/ LM FDL Angles			IMU Gimbal Angles			Look Angles to Earth		Look Angles Other Vehicle		CSM HGA Pointing Angles/LM S-band Pointing Angles	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
145:11:33	LM acquire MSFN line of sight	LM	56.1	-7.0	114.7	240.2	0.0	0.0	240.2	0.0	0.0	148.7	12.2	90.0	180.0	**	**
145:17:39	First LM braking burn ignition (CSM/LM range = 3000 ft)	CSM	58.6	-10.6	96.3	338.3	0.0	0.0	8.6	0.0	0.0	21.9	17.2	35.0	180.0	**	**
	Braking burn cutoff	LM	58.1	-10.6	96.3	238.1	0.0	0.0	238.1	0.0	0.0	151.2	7.4	84.6	180.0	**	**
145:17:50	Braking burn cutoff	CSM	58.6	-10.7	95.8	338.9	0.0	0.0	8.6	0.0	0.0	21.9	17.2	34.8	180.0	**	**
		LM	58.2	-10.7	95.8	238.2	0.0	0.0	238.2	0.0	0.0	151.1	7.4	84.5	180.0	**	**
145:18:52	Second LM braking burn ignition (CSM/LM range = 1500 ft)	CSM	58.6	-11.2	92.6	307.1	0.0	0.0	333.6	0.0	0.0	56.1	7.5	0.0	0.0	**	**
	Braking burn cutoff	LM	58.4	-11.2	92.6	244.1	0.0	0.0	244.1	0.0	0.0	144.7	13.4	90.0	180.0	**	**
145:19:01	Braking burn cutoff	CSM	58.6	-11.3	92.2	307.5	0.0	0.0	333.6	0.0	0.0	56.1	7.5	0.0	0.0	**	**
		LM	58.4	-11.3	92.2	244.1	0.0	0.0	244.1	0.0	0.0	144.7	13.4	90.2	180.0	**	**
145:20:31	Third LM braking burn ignition (CSM/LM range = 500 ft)	CSM	58.6	-11.9	87.6	312.2	0.0	0.0	333.8	0.0	0.0	56.0	7.5	0.0	0.0	**	**
	Braking burn cutoff	LM	58.5	-11.9	87.6	244.1	0.0	0.0	244.1	0.0	0.0	144.8	13.1	89.9	180.0	**	**
145:20:35	Braking burn cutoff	CSM	58.6	-12.0	87.4	312.4	0.0	0.0	333.8	0.0	0.0	56.0	7.5	0.5	0.0	**	**
		LM	58.5	-12.0	87.4	244.1	0.0	0.0	244.1	0.0	0.0	144.7	13.1	89.9	180.0	**	**
145:21:51	Fourth LM braking burn ignition (CSM/LM range = 100 ft)	CSM	58.6	-12.5	83.5	316.6	0.0	0.0	334.1	0.0	0.0	55.7	7.5	0.0	0.0	**	**
	Braking burn cutoff (CSM/LM range = 90 ft, range rate = 0.2 ft/sec)	LM	58.6	-12.5	83.5	244.4	0.0	0.0	244.4	0.0	0.0	144.5	12.9	89.8	180.0	**	**
145:21:55	Braking burn cutoff (CSM/LM range = 90 ft, range rate = 0.2 ft/sec)	CSM	58.6	-12.6	83.2	316.8	0.0	0.0	334.1	0.0	0.0	55.7	7.5	0.2	0.0	**	**
		LM	58.6	-12.6	83.2	244.4	0.0	0.0	244.4	0.0	0.0	144.5	12.9	89.8	180.0	**	**
145:40:00	CSM/LM docking, inertial attitude hold	CSM	58.5	-12.9	26.7	12.5	0.0	180.0	334.9	0.0	180.0	55.2	187.6	0.0	0.0	-53	349
		LM	58.5	-12.9	26.7	334.9	300.0	180.0	154.9	0.0	120.0	124.8	52.4	0.0	0.0	174	60

* No line of sight

** No HGA/LM S-band steerable line of sight

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 5: CSM/LM Docking to TEI

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n.mi.)	Latitude (deg.)	Longitude (deg.)	Pitch (deg.)	Yaw (deg.)	Roll (deg.)	ICA (deg.)	Gimba Angles MGA (deg.)	OCA (deg.)	Theta (deg.)	Phi (deg.)	Theta (deg.)	Phi (deg.)	Pitch (deg.)	Yaw (deg.)
145:40:00	CSM/LM docking, inertial attitude hold	58.5	-12.9	26.7	12.5	0.0	180.0	334.9	0.0	180.0	55.2	187.6	-93.5	192.7	-53	349
146:10:55	Enter darkness	58.3	7.0	-65.9	106.2	0.0	180.0	334.9	0.0	180.0	55.9	187.6	*	*	-54	348
146:23:09	Lose MSFN line of sight	58.3	13.2	-103.2	143.4	0.0	180.0	334.9	0.0	180.0	*	*	*	*	**	**
146:51:00	Maneuver to LM jettison attitude, inertial attitude hold	58.4	6.9	170.6	251.3	341.9	219.4	358.3	342.0	219.4	*	*	*	*	**	**
146:57:06	Enter sunlight	58.4	2.6	152.4	269.8	341.9	219.4	358.3	342.0	219.4	*	*	75.8	159.3	**	**
147:09:24	Acquire MSFN line of sight	58.4	-6.5	116.0	307.2	341.9	219.4	358.3	342.0	219.4	40.0	175.1	75.8	159.3	-39	5
147:57:00	LM jettison	58.5	-2.1	-29.8	91.6	341.9	219.4	358.3	342.0	219.4	40.7	174.4	75.9	159.3	-41	5
147:58:01	Maneuver to separation burn attitude, CSM separation maneuver, $\Delta V = 1$ ft/sec	58.5	-1.4	-32.8	90.0	0.0	180.0	353.6	0.0	180.0	38.2	190.2	75.4	193.1	-36	352
148:00:00	CSM maneuver to attitude for SXT tracking of LM, line-of-sight maintenance	58.2	0.1	-38.6	8.9	2.0	180.0	266.6	0.0	180.0	124.6	187.8	158.1	216.2	-53	192
148:09:31	Enter darkness	57.9	7.0	-66.8	34.1	0.0	179.9	262.9	0.0	180.0	128.4	188.2	*	*	-50	190
148:21:28	Lose MSFN line of sight	57.6	13.1	-103.3	74.8	0.0	179.9	267.3	0.0	180.0	*	*	*	*	**	**
148:55:44	Enter sunlight	57.7	2.5	151.3	124.7	0.0	179.9	213.1	0.0	180.0	*	*	142.5	338.9	**	**
149:07:45	Acquire MSFN line of sight	58.0	-6.3	115.7	132.2	0.0	179.9	184.1	0.0	179.9	151.8	346.6	114.8	346.1	**	**
150:00:00	Maneuver to rest attitude, inertial attitude hold	58.6	1.2	-44.0	24.9	0.0	123.0	278.1	0.0	123.1	114.3	244.0	148.2	261.6	-24	243
150:08:04	Enter darkness	58.6	7.0	-68.0	49.4	0.0	123.0	278.1	0.0	123.1	114.4	244.0	*	*	-24	243
150:19:43	Lose MSFN line of sight	58.6	13.0	-103.5	84.7	0.0	123.0	278.1	0.0	123.1	*	*	*	*	**	**
150:54:16	Enter sunlight	57.6	2.5	150.3	189.6	0.0	123.0	278.1	0.0	123.1	*	*	148.3	261.6	**	**
151:05:57	Acquire MSFN line of sight	57.3	-6.1	115.7	225.1	0.0	123.0	278.1	0.0	123.1	114.4	244.0	148.3	261.6	-24	243
152:06:36	Enter darkness	58.8	7.0	-69.0	49.3	0.0	123.0	278.1	0.0	123.1	115.5	244.1	*	*	-23	242
152:17:55	Lose MSFN line of sight	58.8	12.9	-103.4	83.6	0.0	123.0	278.1	0.0	123.1	*	*	*	*	**	**
152:52:49	Enter sunlight	57.5	2.5	149.3	189.5	0.0	123.0	278.1	0.0	123.1	*	*	148.3	261.7	**	**
153:04:11	Acquire MSFN line of sight	57.2	-5.9	115.6	224.1	0.0	123.0	278.1	0.0	123.1	115.5	244.2	148.3	261.7	-23	242
154:05:09	Enter darkness	59.0	7.0	-70.0	49.3	0.0	123.0	278.1	0.0	123.1	116.6	244.3	*	*	-23	241
154:16:09	Lose MSFN line of sight	59.0	12.8	-103.5	82.6	0.0	123.0	278.1	0.0	123.1	*	*	*	*	**	**
154:51:21	Enter sunlight	57.4	2.5	148.3	189.4	0.0	123.0	278.1	0.0	123.1	116.6	244.3	148.4	261.7	**	**
155:02:25	Acquire MSFN line of sight	57.0	-5.7	115.5	223.1	0.0	123.0	278.1	0.0	123.1	117.7	244.5	*	*	-22	240
156:03:40	Enter darkness	59.2	7.0	-71.0	49.2	0.0	123.0	278.1	0.0	123.1	*	*	*	*	**	**
156:14:22	Lose MSFN line of sight	59.2	12.7	-103.5	81.6	0.0	123.0	278.1	0.0	123.1	*	*	*	*	**	**
156:49:54	Enter sunlight	57.4	2.5	147.3	189.4	359.9	122.9	278.1	0.0	123.1	*	*	148.5	261.8	**	**
157:00:39	Acquire MSFN line of sight	56.9	-5.5	115.4	222.1	359.9	122.9	278.1	0.0	123.1	117.7	244.5	148.5	261.8	-22	240
158:02:13	Enter darkness	59.3	7.1	-72.1	49.1	359.9	122.9	278.1	0.0	123.1	118.7	244.6	*	*	-22	239
158:06:00	Terminate rest attitude, maneuver for IMU realignment, inertial attitude hold	59.4	9.4	-83.4	60.8	44.9	179.8	278.1	45.0	180.0	104.9	206.0	116.6	238.1	-60	239
158:12:24	Lose MSFN line of sight	59.4	12.5	-103.0	80.1	44.9	179.8	278.1	45.0	180.0	*	*	*	*	**	**
158:15:00	Begin IMU realignment to plane change 2 REFSMMA T***	59.4	13.4	-111.0	88.0	44.9	179.8	326.4	24.4	56.9	*	*	*	*	**	**

* No line of sight

** No HGA line of sight

*** Gimbal angles reflect change in REFSMMA T.

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 5: CSM/LM Docking to TEI
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HCA Pointing Angles	
		Altitude (m mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	TGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
158:35:00	Maneuver to plane change 2 burn attitude, inertial attitude hold	58.3	11.1	-173.4	140.2	85.5	138.5	0.0	0.0	0.0	*	*	*	*	**	**
158:48:27	Enter sunlight	57.3	2.5	146.2	181.1	85.5	138.5	0.0	0.0	0.0	*	*	81.5	291.0	**	**
158:58:44	Acquire MSFN line of sight	56.7	-5.2	115.8	212.3	85.5	138.5	0.0	0.0	0.0	86.1	259.0	81.5	291.0	-10	274
159:01:46	Plane change 2 burn ignition	56.6	-7.2	106.7	221.6	85.5	138.5	0.0	0.0	0.0	86.0	259.0	81.5	291.0	-10	274
159:02:04	Plane change 2 burn cutoff	56.6	-7.4	105.8	281.6	86.8	79.3	0.0	0.1	0.0	85.9	259.0	81.4	291.1	-10	274
159:07:00	Maneuver for IMU realignment, inertial attitude hold	56.5	-9.4	90.7	285.9	0.4	89.4	273.4	0.0	359.9	78.9	273.5	110.2	280.5	3	281
159:08:00	Begin IMU realignment to photography REFSMMAT***	56.5	-9.7	87.6	289.0	0.4	89.4	306.8	0.4	89.4	78.9	273.5	110.2	280.5	3	281
159:26:00	Maneuver for high resolution photography of Lalande, inertial attitude hold	56.6	-10.3	31.7	274.0	0.3	0.1	257.0	0.3	0.1	128.9	3.9	158.3	26.1	**	**
159:36:14	Begin Lalande high resolution photography at TCA - 3 min, maintain constant line of sight to landmark	57.0	-6.4	0.4	325.1	0.3	0.1	257.0	0.3	0.1	129.2	4.0	158.3	26.2	**	**
159:40:14	Terminate Lalande high resolution photography at TCA + 1 min, inertial attitude hold	57.2	-4.3	-11.7	219.8	0.7	0.1	139.5	0.8	0.1	113.1	176.3	82.1	170.7	-67	171
159:51:00	Maneuver for IMU realignment, inertial attitude hold	57.8	2.0	-43.9	16.0	0.0	180.0	263.0	0.0	180.0	123.5	183.5	152.9	200.4	-56	186
160:00:37	Enter darkness	58.1	7.1	-72.8	45.2	0.0	180.0	263.0	0.0	180.0	123.7	183.6	*	*	-56	186
160:10:28	Lose MSFN line of sight	58.3	10.5	-103.0	75.1	0.0	180.0	263.0	0.0	180.0	*	*	*	*	**	**
160:20:00	Begin IMU realignment	58.3	11.2	-132.5	104.0	0.0	180.0	263.0	0.0	180.0	*	*	*	*	**	**
160:46:00	Maneuver to strip photography attitude, local attitude hold	57.1	0.5	148.4	270.0	0.0	0.0	350.0	0.0	0.0	*	*	*	*	**	**
160:47:02	Enter sunlight	57.0	-0.1	145.3	270.0	0.0	0.0	346.9	0.0	0.0	*	*	70.8	9.7	**	**
160:56:49	Acquire MSFN line of sight	56.5	-5.6	115.9	270.0	0.0	0.0	317.1	0.0	0.0	69.6	3.2	100.2	9.3	**	**
161:54:00	Terminate strip photography, inertial attitude hold	58.1	4.6	-58.7	270.0	0.0	0.0	143.1	0.0	0.0	115.4	176.7	85.7	170.8	-64	173
161:59:03	Enter darkness	58.3	7.1	-73.9	285.3	0.0	0.0	143.1	0.0	0.0	115.3	176.7	*	*	-64	173
162:08:33	Lose MSFN line of sight	58.6	10.5	-103.0	314.1	0.0	0.0	143.1	0.0	0.0	*	*	*	*	**	**
162:45:28	Enter sunlight	57.0	-0.8	144.2	66.2	0.0	0.0	143.1	0.0	0.0	*	*	85.7	170.8	**	**
162:54:58	Acquire MSFN line of sight	56.4	-5.5	115.7	95.1	0.0	0.0	143.1	0.0	0.0	115.3	176.6	85.6	170.8	-64	173
163:16:00	Maneuver for high resolution photography of Descartes, inertial attitude hold	56.1	-11.3	50.9	299.3	359.9	0.0	283.2	359.9	0.0	104.8	3.1	133.6	12.6	**	**
163:24:24	Begin Descartes high resolution photography at TCA - 3 min, maintain constant line of sight to landmark	56.4	-9.9	24.8	324.9	359.9	0.0	283.2	359.9	0.0	105.0	3.2	133.6	12.6	**	**
163:28:24	Terminate Descartes high resolution photography at TCA + 1 min, inertial attitude hold	56.6	-8.5	12.5	220.5	359.8	0.0	166.7	359.8	0.0	138.3	175.6	108.9	170.4	-42	176
163:33:00	Maneuver for high resolution photography of Fra Mauro, inertial attitude hold	56.7	-7.8	7.6	318.0	359.8	0.0	250.1	359.8	0.0	138.2	4.4	164.6	35.9	**	**

* No line of sight

** No HCA line of sight

*** Gimbal angles reflect change in REFSMMAT.

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 5: CSM/LM Docking to TEI
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth			Look Angles to Sun			CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	ICA (deg)	MCA (deg)	OCA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
163:35:16	Begin Fra Mauro high resolution photography at TCA - 3 min, maintain constant line of sight to landmark	57.1	-5.3	-8.4	324.9	339.8	0.0	250.1	359.8	0.0	138.2	4.4	164.6	35.8	**	**	**	**
163:39:16	Terminate Fra Mauro high resolution photography at TCA + 1 min, inertial attitude hold	57.4	-3.0	-20.4	221.9	359.6	359.9	135.0	359.6	359.9	106.5	177.0	77.7	170.6	-73	170		
163:45:00	Maneuver for IMU realignment, inertial attitude hold	57.8	0.3	-37.5	160.4	3.0	0.0	56.0	0.0	0.0	27.5	173.3	9.3	80.6	-28	3		
163:57:27	Enter darkness	58.6	7.1	-74.9	198.2	0.0	0.0	56.0	0.0	0.0	27.4	173.3	*	*	-27	3		
164:03:00	Begin IMU realignment	58.7	9.4	-91.8	215.0	0.0	0.0	56.0	0.0	0.0	27.3	173.3	*	*	-27	3		
164:06:42	Lose MSFN line of sight	58.8	10.4	-103.2	226.2	0.0	0.0	56.0	0.0	0.0	*	*	*	*	**	**		
164:43:53	Enter sunlight	56.8	-0.1	143.2	339.1	0.0	0.0	56.0	0.0	0.0	*	*	9.3	80.5	**	**		
164:46:00	Maneuver to landmark tracking attitude, local attitude hold	56.7	-1.3	136.9	338.0	0.0	0.0	48.5	0.0	0.0	*	*	12.8	45.7	**	**		
164:53:10	Acquire MSFN line of sight	56.2	-5.4	115.4	338.0	0.0	0.0	26.7	0.0	0.0	3.7	55.7	32.1	17.4	**	**		
165:42:00	Terminate landmark tracking, maneuver to IMU realignment attitude, inertial attitude hold	57.8	-0.5	-34.3	338.0	0.0	180.0	238.0	0.0	180.0	151.6	186.6	170.8	267.8	-27	183		
165:55:52	Enter darkness	58.7	7.2	-76.0	20.1	0.0	180.0	238.0	0.0	180.0	151.8	186.6	*	*	-27	183		
166:04:58	Lose MSFN line of sight	59.0	10.4	-103.7	47.6	0.0	180.0	238.0	0.0	180.0	*	*	*	*	**	**		
166:05:00	Begin IMU realignment	59.0	10.4	-103.8	47.7	0.0	180.0	238.0	0.0	180.0	*	*	*	*	**	**		
166:42:18	Enter sunlight	56.7	-0.8	142.2	160.9	0.0	180.0	238.0	0.0	180.0	*	*	170.8	268.0	**	**		
166:45:00	Maneuver to landmark tracking attitude, local attitude hold	56.5	-1.7	134.1	338.0	0.0	0.0	46.8	0.0	0.0	17.2	169.4	14.1	40.6	-16	3		
166:51:25	Acquire MSFN line of sight	56.0	-5.3	114.8	338.0	0.0	0.0	27.3	0.0	0.0	4.1	50.4	31.6	17.7	**	**		
167:40:00	Terminate landmark tracking, maneuver for HGA communications, inertial attitude hold	57.9	-0.7	-34.1	338.0	0.0	180.0	239.3	0.0	180.0	151.3	186.7	170.7	260.3	-28	184		
167:54:17	Enter darkness	58.9	7.2	-77.0	21.3	0.0	180.0	239.3	0.0	180.0	151.5	186.7	*	*	-27	183		
168:03:02	Lose MSFN line of sight	59.2	10.3	-103.7	47.8	0.0	180.0	239.3	0.0	180.0	*	*	*	*	**	**		
168:36:00	Maneuver to strip photography attitude, local attitude hold	57.1	2.7	155.4	258.0	0.0	0.0	349.5	0.0	0.0	*	*	*	*	**	**		
168:40:44	Enter sunlight	56.6	-1.0	141.2	258.0	0.0	0.0	335.1	0.0	0.0	*	*	82.8	9.2	**	**		
168:49:14	Acquire MSFN line of sight	55.9	-5.0	115.6	258.0	0.0	0.0	309.2	0.0	0.0	81.8	3.2	108.3	9.6	**	**		
169:47:00	Terminate strip photography, maneuver for IMU realignment, inertial attitude hold	58.8	4.3	-60.8	33.0	0.0	180.0	268.3	0.0	180.1	123.7	183.9	148.3	197.6	-55	186		
169:52:42	Enter darkness	59.2	7.2	-78.0	50.3	0.0	180.0	268.3	0.0	180.1	123.7	183.9	*	*	-55	186		
170:00:58	Lose MSFN line of sight	59.5	10.2	-103.2	75.3	0.0	180.0	268.3	0.0	180.1	*	*	*	*	**	**		
170:02:00	Begin IMU realignment to TEI REFSMMAT***	59.5	10.4	-106.4	78.4	0.0	180.0	145.3	4.4	183.4	*	*	*	*	**	**		

* No line of sight

** No HGA line of sight

*** Gimbal angles reflect change in REFSMMAT.

Table I. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 5: CSM/LM Docking to TEI
(Continued)

Mission Time (hr:min:sec)	Event	Selenographic Position			CSM Local			IMU			Look Angles to Earth		Look Angles to Sun		CSM HGA Pointing Angles	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
170:39:10	Enter sunlight	56.5	-0.1	140.1	191.2	0.0	180.0	145.3	4.4	183.4	*	*	148.3	197.6	**	**
170:47:36	Acquire MSFN line of sight	55.7	-5.0	114.8	216.8	0.0	180.0	145.3	4.4	183.4	123.7	183.9	148.3	197.6	-55	186
171:51:00	Maneuver to TEI burn attitude, inertial attitude hold	59.4	7.1	-78.7	261.4	6.6	180.7	357.0	1.1	180.1	86.3	356.4	61.3	352.5	**	**
171:51:06	Enter darkness	59.4	7.2	-79.0	261.7	6.6	180.7	357.0	1.1	180.1	86.3	356.4	*	*	**	**
171:59:09	Lose MSFN line of sight	59.7	10.1	-103.5	286.1	6.6	180.7	357.0	1.1	180.1	*	*	*	*	**	**
172:21:15	TEI burn ignition	58.4	8.5	-171.6	353.0	6.6	180.7	357.0	1.1	180.1	*	*	*	*	**	**

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(d) Transearth

Mission Time (hr:min:sec)	Event	IMU			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		CSM HGA Pointing Angles	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
172:23:24	TEI cutoff inertial attitude hold	359.9	358.6	180.0	*	*	94.1	359.5	*	*	**	**
172:34:00	Acquire MSFN line of sight	359.9	358.6	180.0	89.4	356.4	137.6	357.0	64.4	351.5	**	**
172:46:00	Maneuver to TV attitude	200.0	4.0	187.0	71.7	175.4	2.7	355.8	96.8	180.5	-71	12
173:15:00	Maneuver to IMU realignment attitude; change to PTC REFSMMAT							Maneuver spacecraft as required				
173:38:00	Begin PTC	270.0	0.0	0.0	86.5	276.2	96.9	21.0	90.0	250.6	6	274
185:44:00	Terminate PTC; realign IMU							Maneuver spacecraft as required				
187:21:15	Fifth midcourse correction							Maneuver spacecraft as required				
187:44:00	Begin PTC	270.0	0.0	0.0	87.1	275.4	98.4	44.5	90.0	250.0	6	272
189:00:00	Terminate PTC; maneuver to optics calibration attitude							Maneuver spacecraft as required				
189:10:00	Maneuver to sighting attitude for star-earth horizon sighting							Maneuver spacecraft as required				
190:00:00	Begin PTC	270.0	0.0	0.0	87.2	275.1	98.4	45.0	90.0	249.9	6	272
195:00:00	Terminate PTC; maneuver to optics calibration attitude							Maneuver spacecraft as required				
195:10:00	Maneuver to sighting attitude for star-earth horizon sightings							Maneuver spacecraft as required				
196:00:00	Begin PTC	270.0	0.0	0.0	87.5	275.2	98.4	46.2	90.0	249.7	6	272
213:00:00	Terminate PTC; maneuver to optics calibration attitude							Maneuver spacecraft as required				
213:10:00	Maneuver to sighting attitude for star-earth horizon navigation							Maneuver spacecraft as required				
214:00:00	Begin PTC	270.0	0.0	0.0	88.6	271.2	98.3	49.3	90.0	248.9	2	272
217:00:00	Terminate PTC; maneuver to optics calibration attitude							Maneuver spacecraft as required				
217:10:00	Maneuver to sighting attitude for star-earth horizon navigation							Maneuver spacecraft as required				
220:00:00	Maneuver to optics calibration attitude							Maneuver spacecraft as required				
220:10:00	Maneuver to sighting attitude for star-earth horizon sighting							Maneuver spacecraft as required				

* No line of sight

** No HGA line of sight

Table I. Spacecraft Attitude and Trajectory Data
(d) Transearth (Continued)

Mission Time (hr:min:sec)	Event	IMU			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun		CSM HGA Pointing Angles	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Pitch (deg)	Yaw (deg)
221:30:00	Reaction IMU											
222:21:48	Sixth midcourse correction											
223:15:00	Maneuver to TV attitude											
224:00:00	Resume PTC	270.0	0.0	0.0	89.6	268.2	98.0	51.6	90.0	248.5	-1	270
236:00:00	Terminate PTC; maneuver to optics calibration attitude											
236:10:00	Maneuver to sighting attitude for star-earth horizon sighting											
237:00:00	Resume PTC	270.0	0.0	0.0	92.8	258.9	97.3	55.9	90.0	247.9	-11	268
239:45:00	Terminate PTC; realign IMU to entry REFSMMAT											
241:21:48	Seventh midcourse correction											
242:36:00	Maneuver to entry attitude	156.0	0.0	0.0	127.4	180.0	58.6	342.3	115.6	173.1	-51	180
243:00:00	Realign IMU											
244:03:00	Maneuver to CM/SM separation attitude	266.0	315.0	0.0	78.3	12.0	53.8	162.3	124.5	329.9	**	**
244:10:00	CM/SM separation	266.0	315.0	0.0	66.5	25.8	54.0	162.3	124.5	329.9	**	**
244:13:00	Maneuver to entry attitude	156.0	0.0	0.0	155.9	0.0	58.4	343.5	115.7	173.1	**	**
244:21:48	Entry interface (ALT = 400,000 feet)	156.0	0.0	0.0	114.0	0.0	57.9	343.6	115.7	173.1	**	**

** No HGA line of sight

TABLE II.- MISSION H-1 IMU MATRICES; LAUNCH DATE

NOVEMBER 14, 1969; 72-DEGREE FLIGHT AZIMUTH

Launch Pad

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}^* = \begin{bmatrix} 0.70768870 & -0.65236370 & 0.27128991 \\ -0.16414623 & -0.52528436 & -0.83494449 \\ 0.68719184 & 0.54634959 & -0.47882090 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}^{**}$$

Passive Thermal Control

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.64278761 & 0.70281115 & 0.30476315 \\ 0.76604445 & 0.58972856 & 0.25572665 \\ 0.0 & 0.39784003 & -0.91745479 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Lunar Landing Site

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.88000242 & 0.45578804 & 0.13361524 \\ -0.16095158 & -0.55083074 & 0.81895062 \\ 0.44686726 & 0.69917292 & 0.55809218 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Plane Change 1

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.09090266 & -0.52789263 & 0.84443238 \\ 0.96207242 & -0.26555166 & -0.06244173 \\ 0.25720295 & 0.80672900 & 0.53201029 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Lunar Lift-off

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.98074201 & 0.19321298 & 0.02852869 \\ -0.08950766 & -0.57447133 & 0.81361606 \\ 0.17359009 & 0.79539389 & 0.58070219 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

* $\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM}$ Components of a unit vector in the stable member system

** $\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$ Components of a unit vector in the earth centered inertial system

TABLE II.- MISSION H-1 IMU MATRICES; LAUNCH DATE NOVEMBER 14, 1969;

72-DEGREE FLIGHT AZIMUTH - Concluded

Plane Change 2

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.07230054 & -0.51169582 & 0.85611916 \\ 0.78648257 & 0.49862422 & 0.36444349 \\ -0.61336596 & 0.69967226 & 0.36638904 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Photography

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} -0.99920070 & -0.00131239 & -0.03995296 \\ -0.03280089 & -0.54435646 & 0.83821248 \\ -0.02284871 & 0.83885300 & 0.54387832 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Transearth Injection

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} 0.55466947 & -0.75341615 & -0.35313721 \\ -0.09108687 & -0.47683697 & 0.87425951 \\ -0.82707010 & -0.45275890 & -0.33311322 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

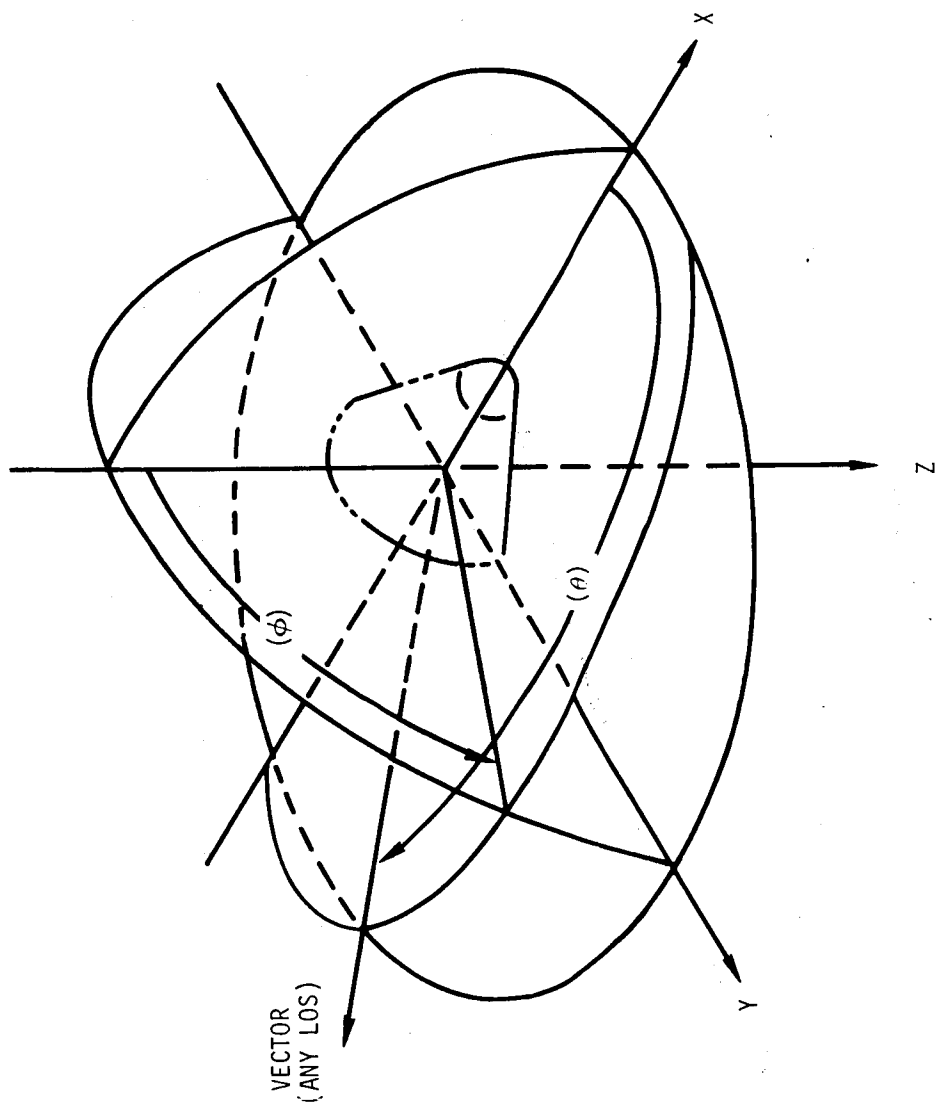
Entry

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} 0.17049641 & -0.97769310 & -0.12266696 \\ 0.21985061 & 0.15909631 & -0.96247289 \\ 0.96051897 & 0.13712977 & 0.24207177 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ECI}$$

Table III. Mission H-1 Candidate Lunar Landmark Tracking Sites

<u>Landmark</u>	<u>Longitude (deg)</u>	<u>Latitude (deg)</u>	<u>Elevation (n mi)</u>
Site 7	23.3919 W	2.9822 S	-1.2816
H-1	15.250 W	1.517 S	-1.9438
193	23.229 W	3.437 S	-1.37
CP1	112.000 E	5.667 S	0.0
CP2	56.183 E	10.250 S	-0.81
DE1	15.550 E	8.883 S	-1.7
FM1	17.3305 W	3.228 S	-1.5631
Fra Mauro	17.550 W	3.617 S	-1.8628
Descartes	15.517 E	8.858 S	-1.7
Theophilus	27.0 E	10.0 S	0.0
Lalande	8.667 W	4.783 S	-0.3239
Lansberg A	31.150 W	0.150 N	-0.54

Note: Elevations are based on a mean lunar radius of
938.4449184 nautical miles.



θ - SMALLEST ANGLE FROM X-BODY AXIS TO VECTOR
 ϕ - MEASURED FROM -Z-BODY AXIS POSITIVELY ABOUT X-BODY
 AXIS TO VECTOR PROJECTION IN Y-Z PLANE

Figure 1. Spacecraft Look Angles

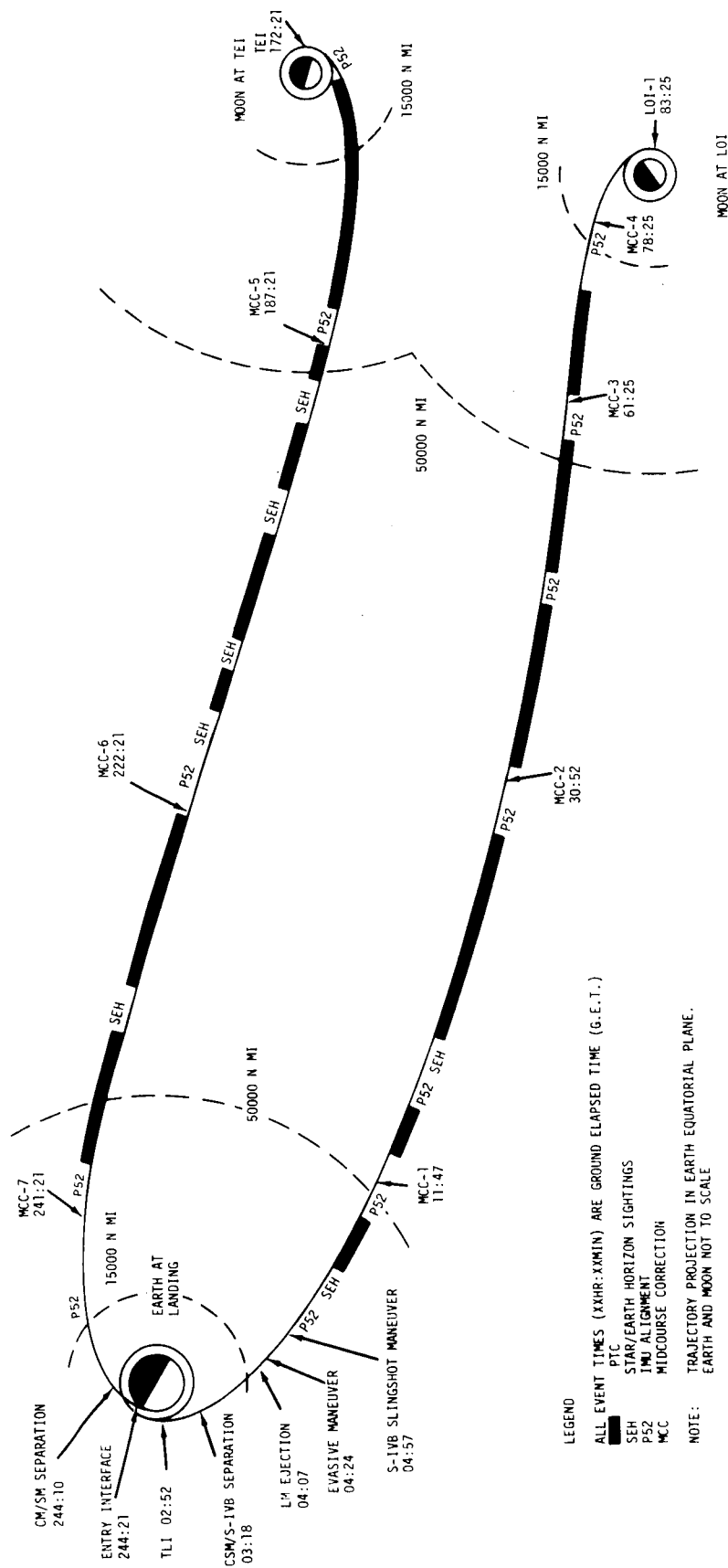


Figure 2. Cislunar Trajectory and Event Profile

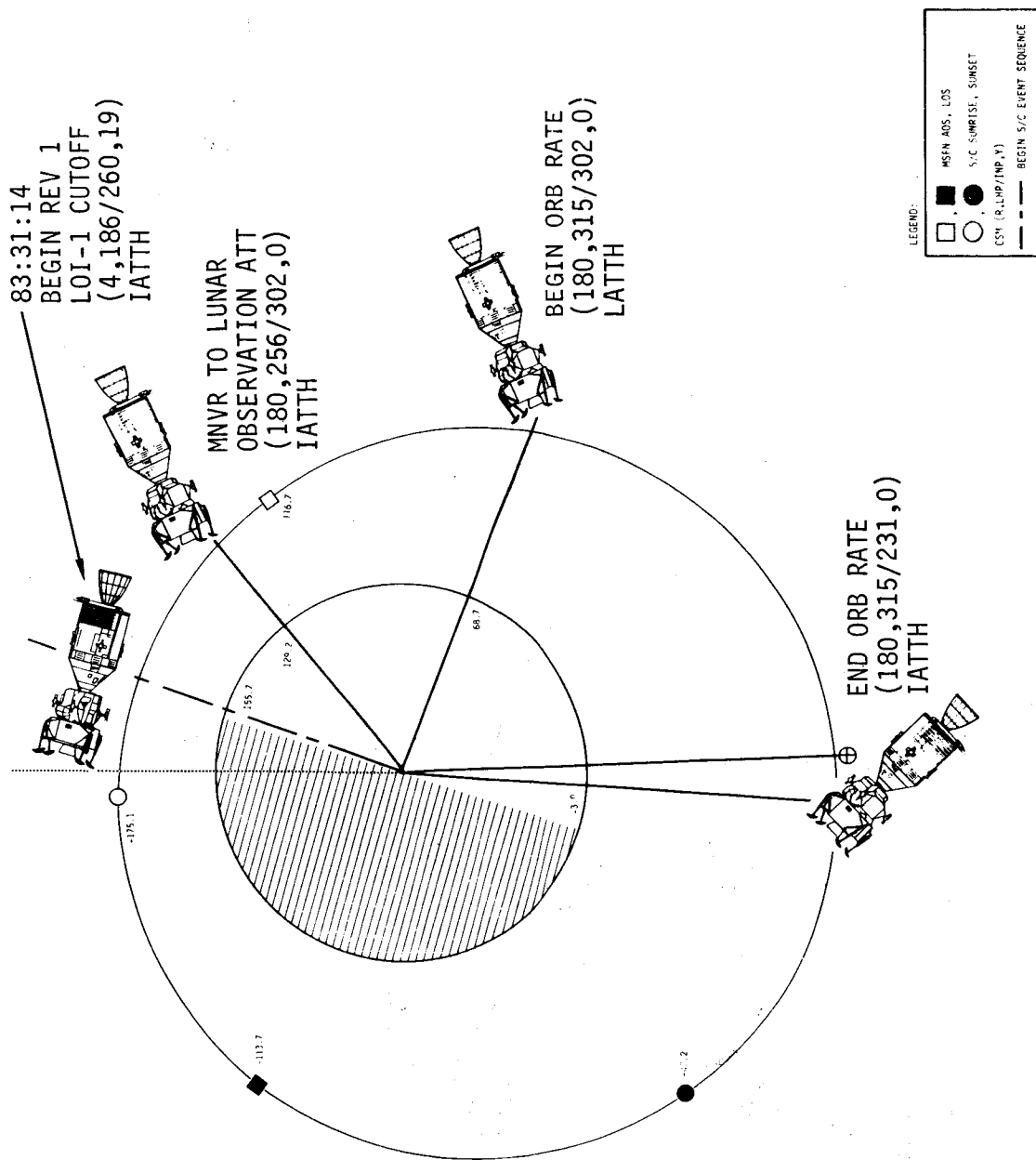
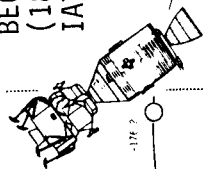
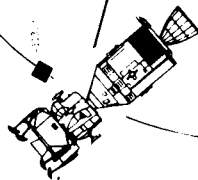


Figure 3. First Revolution Major Events and Attitudes

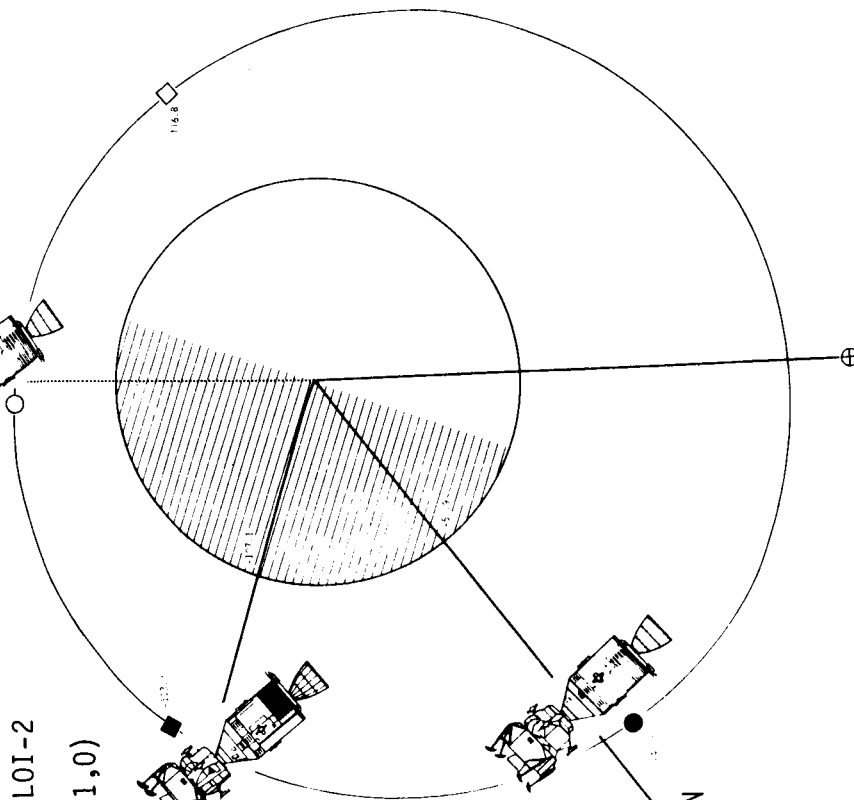
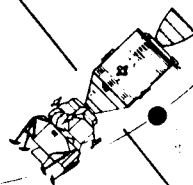
85:31:20
 BEGIN REV 2
 (180,131/231,0)
 IATTH



MNVR TO LOI-2
 BURN ATT
 (0,58/231,0)
 IATTH



BEGIN IMU REALIGN
 (180,3/231,0)



LEGEND:

□	MSFN AOS, LOS
●	S/C SUNRISE, SUNSET
(R,LWP/IMP,Y)	

Figure 4. Second Revolution Major Events and Attitudes

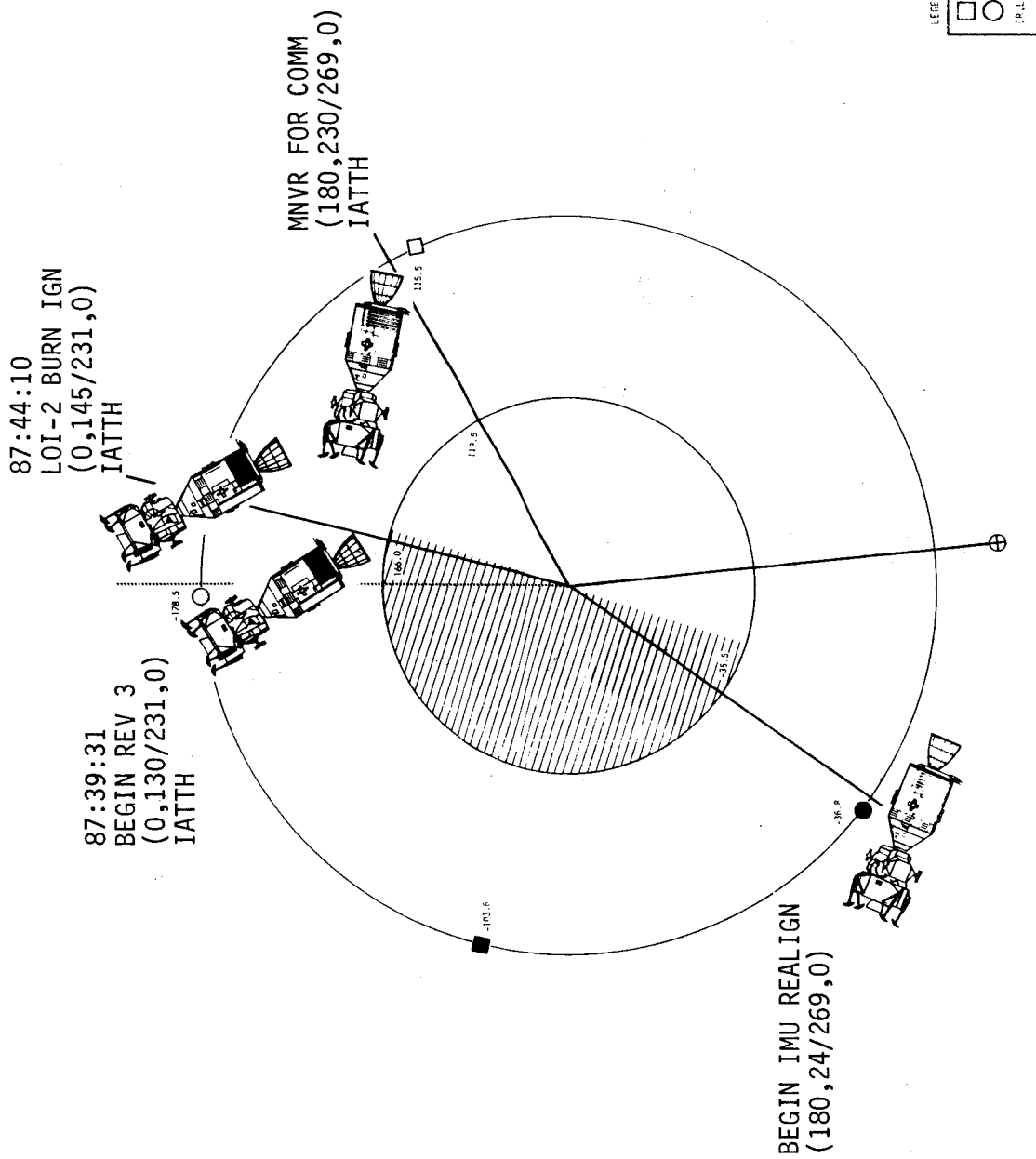


Figure 5. Third Revolution Major Events and Attitudes

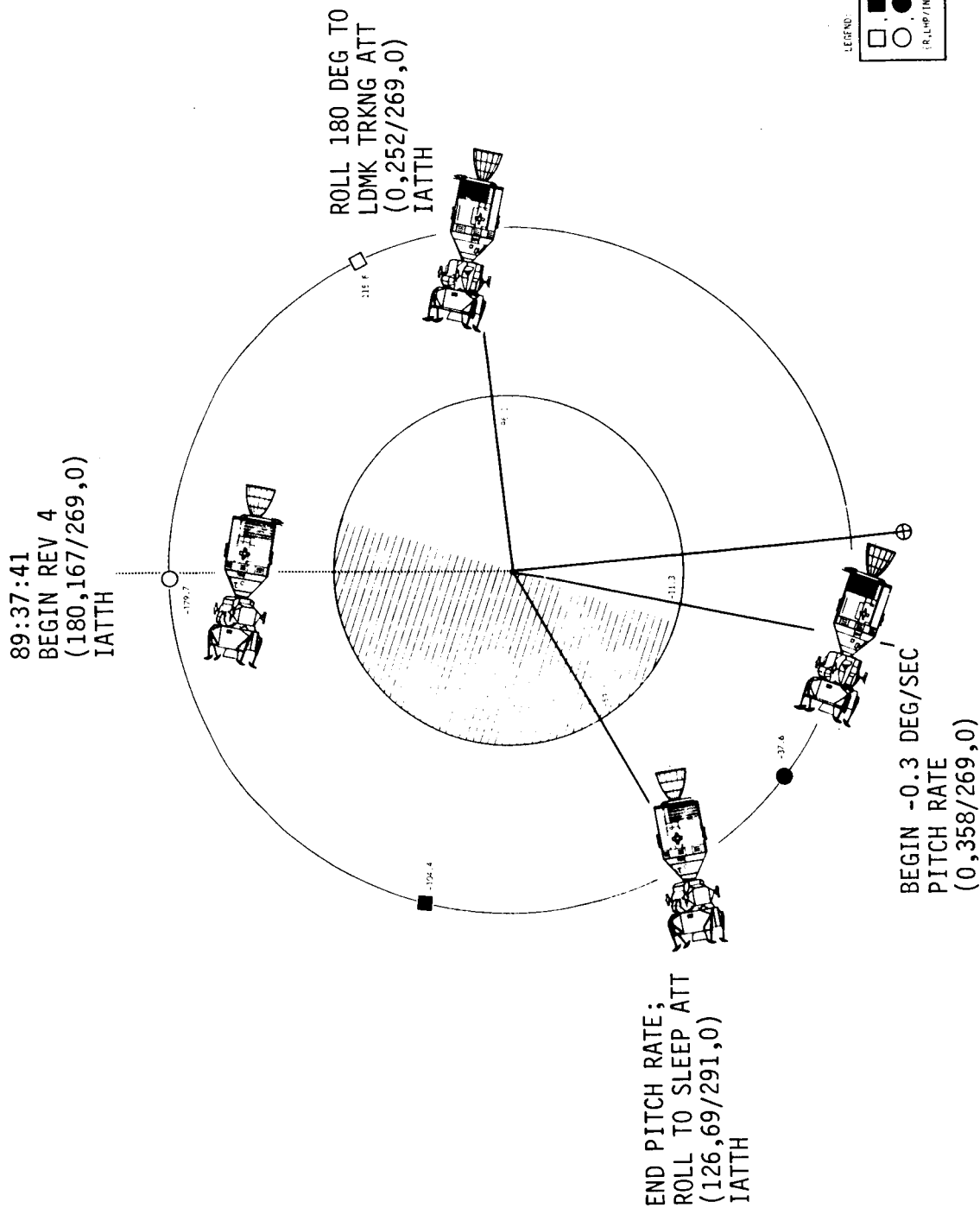


Figure 6. Fourth Revolution Major Events and Attitudes

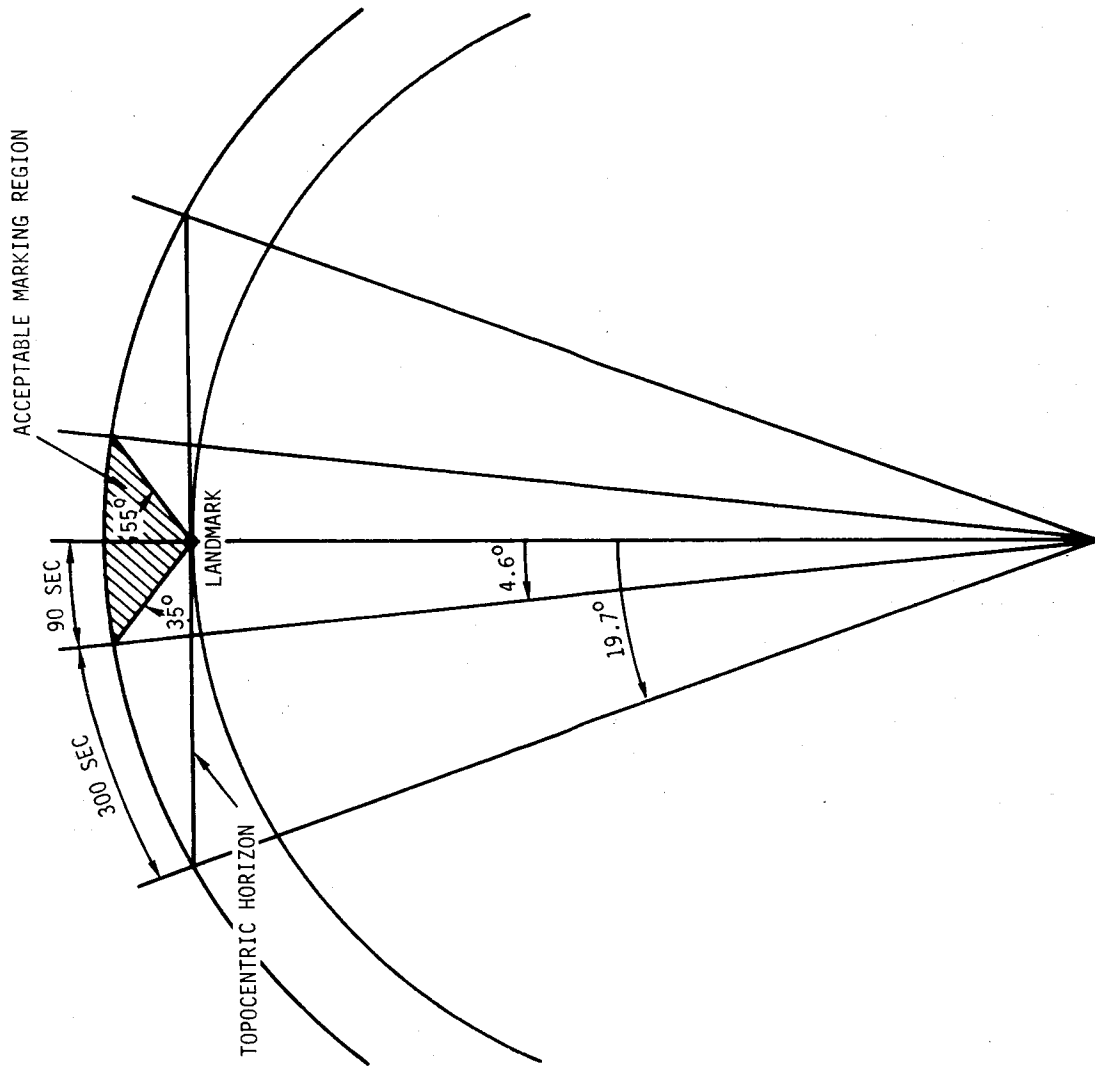


Figure 7. Landmark Tracking Geometry for a 60-Nautical Mile Circular Lunar Orbit

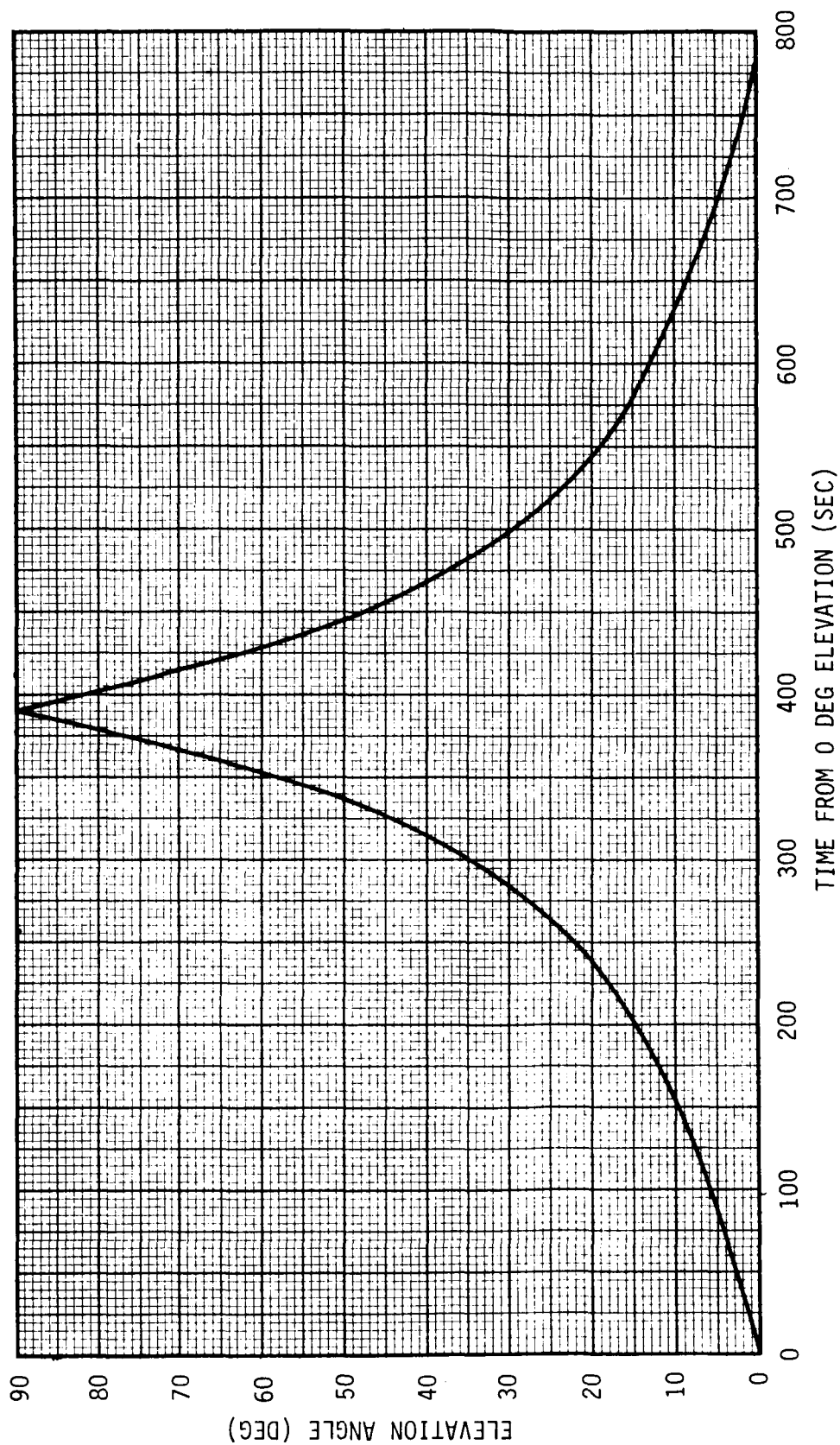


Figure 8. Elevation Angle versus Time Curve for In-plane Landmark

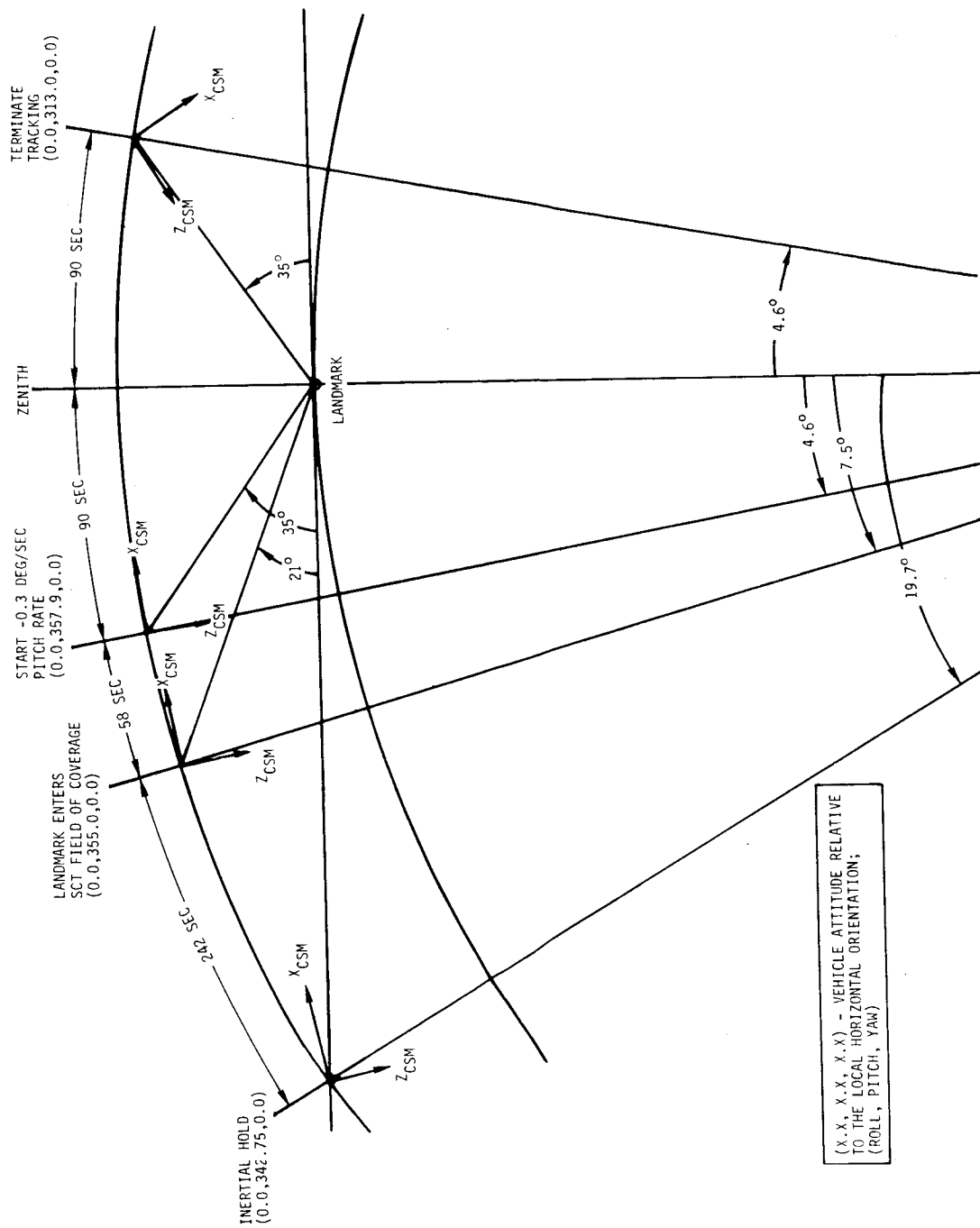


Figure 9. Tracking Geometry for Mode I Landmark Tracking

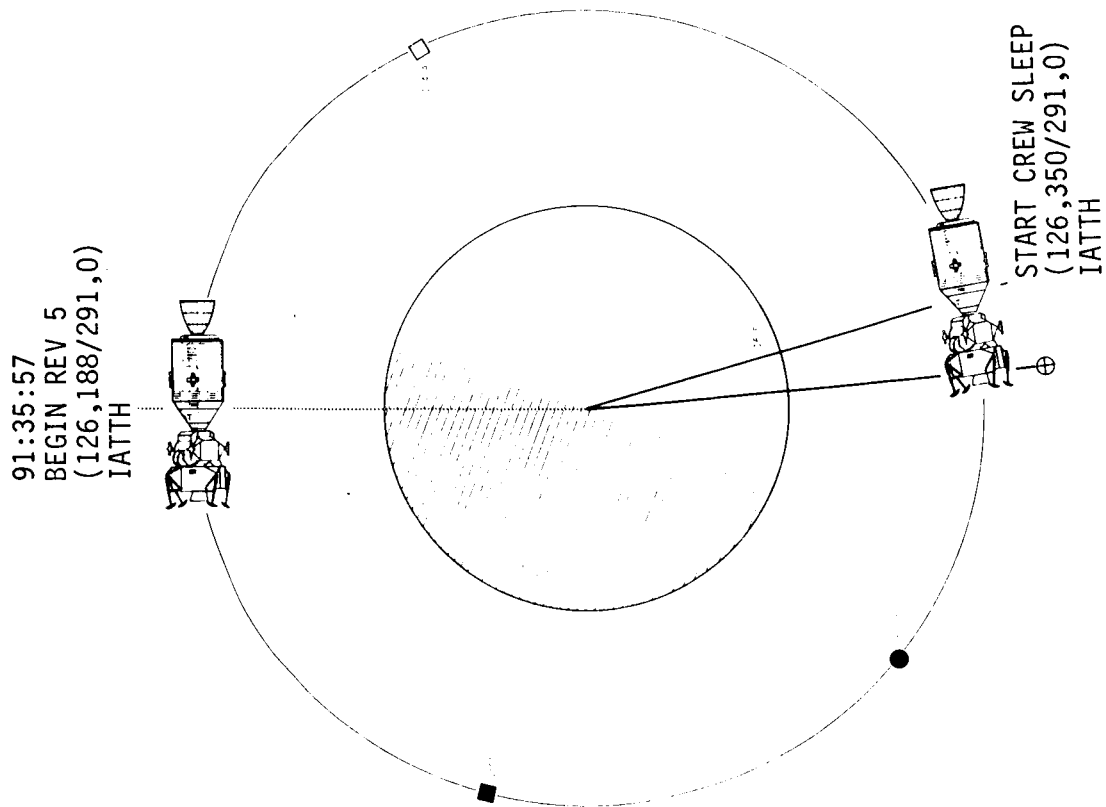


Figure 10. Fifth Revolution Major Events and Attitudes

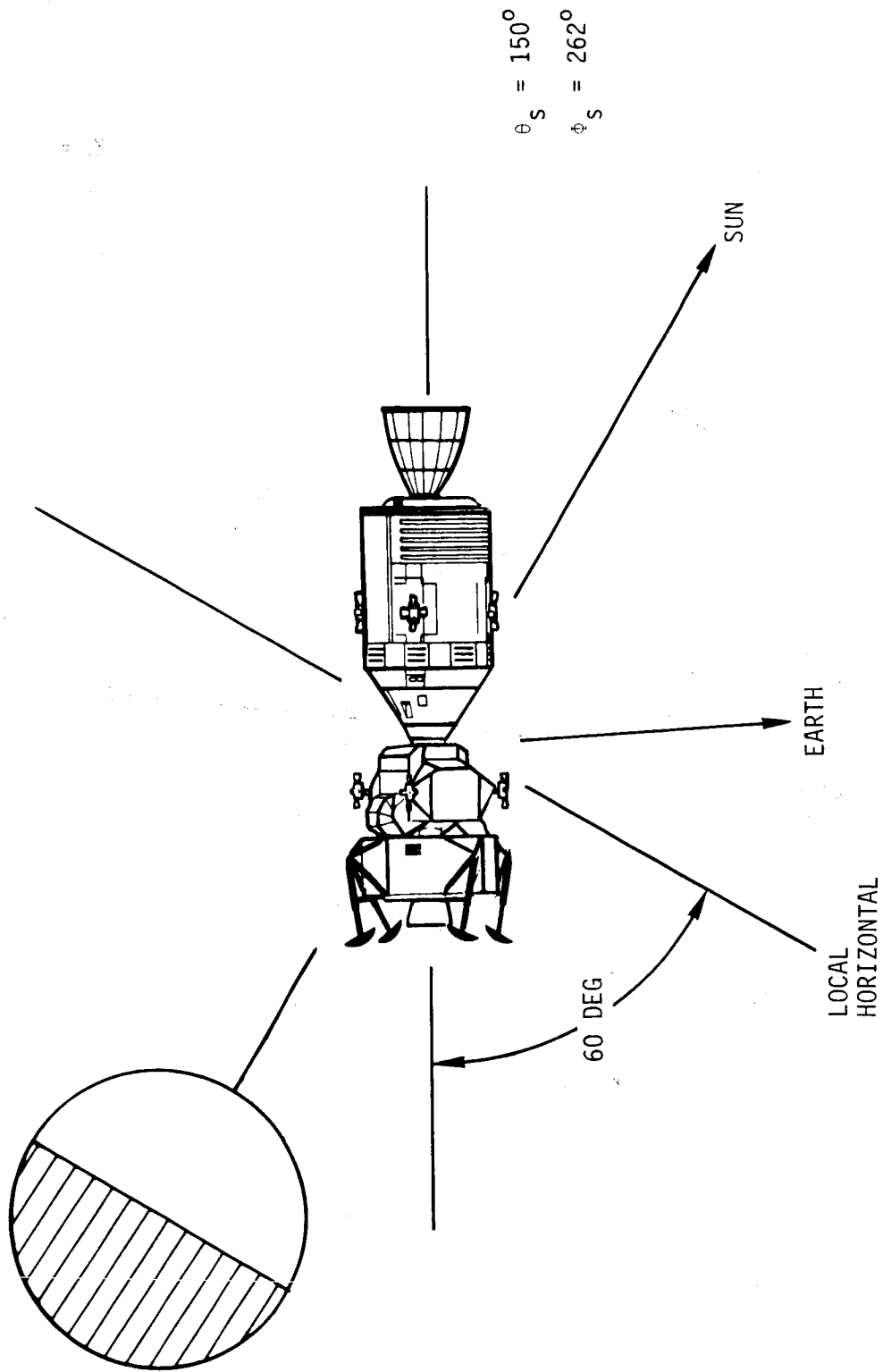


Figure 11. Lunar Orbit Sleep Geometry

93:34:14
 BEGIN REV 6
 (126,187/291,0)
 IATTH

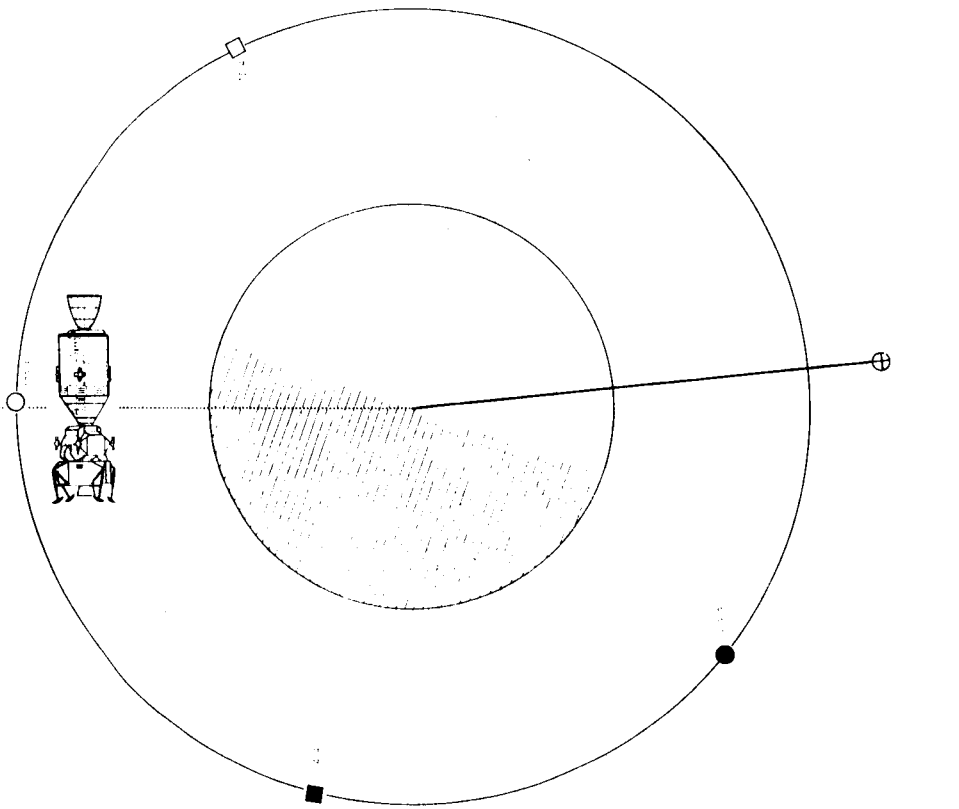


Figure 12. Sixth Revolution Major Events and Attitudes

95:32:30
 BEGIN REV 7
 (126,185/291,0)
 IATH

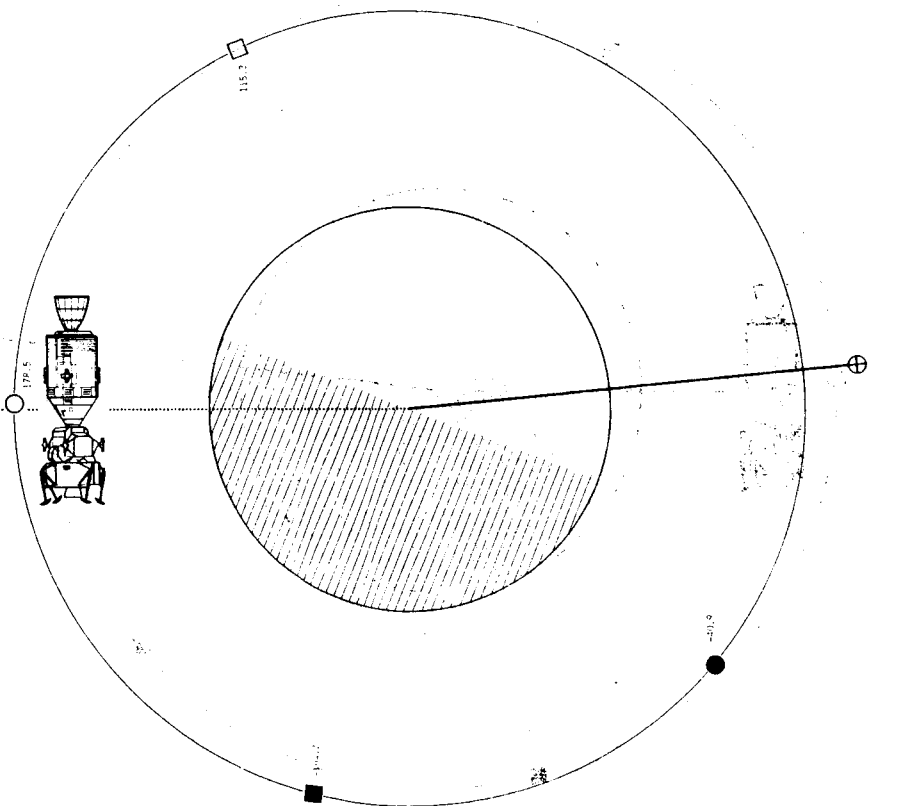


Figure 13. Seventh Revolution Major Events and Attitudes

☐ MSFN ADS, LOS
☐ S/C SUNRISE, SUNSET
 (R, LHP / INP, Y)

•

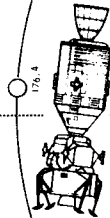
•

•

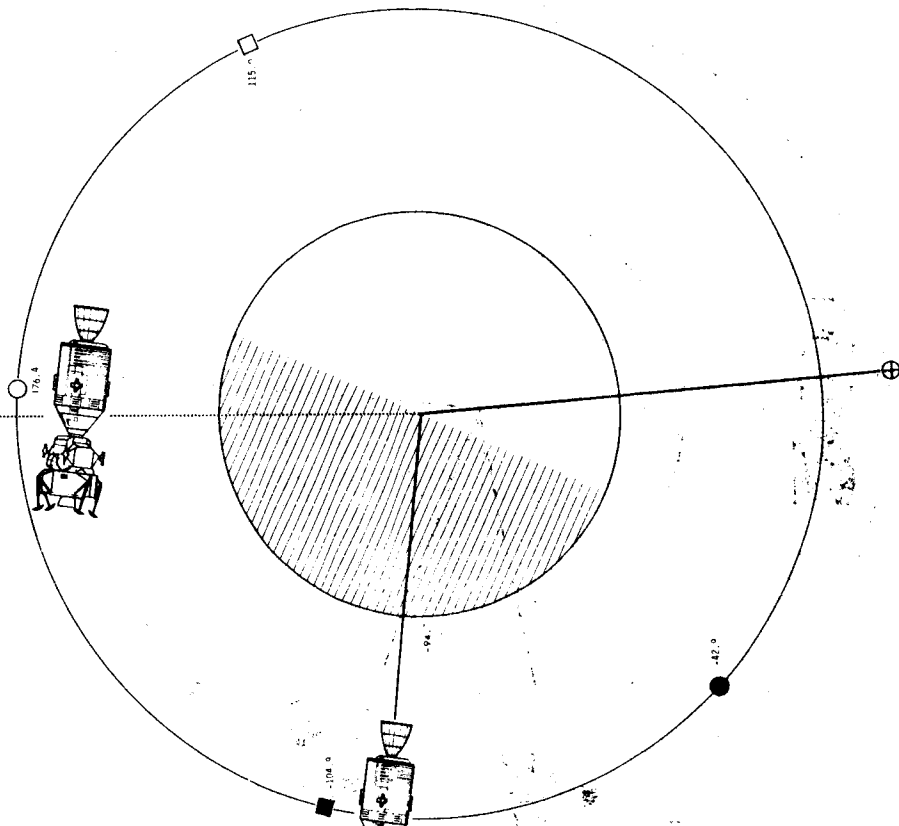
•

•

99:29:03
 BEGIN REV 9
 (126,183/291,0)
 IATH



END CREW SLEEP
 (126,99/291,0)
 IATH



LEGEND:

■	MSFN ADS, LOS
●	S/C SUNRISE, SUNSET
□	(P, LHP/IMP, Y)

Figure 15. Ninth Revolution Major Events and Attitudes

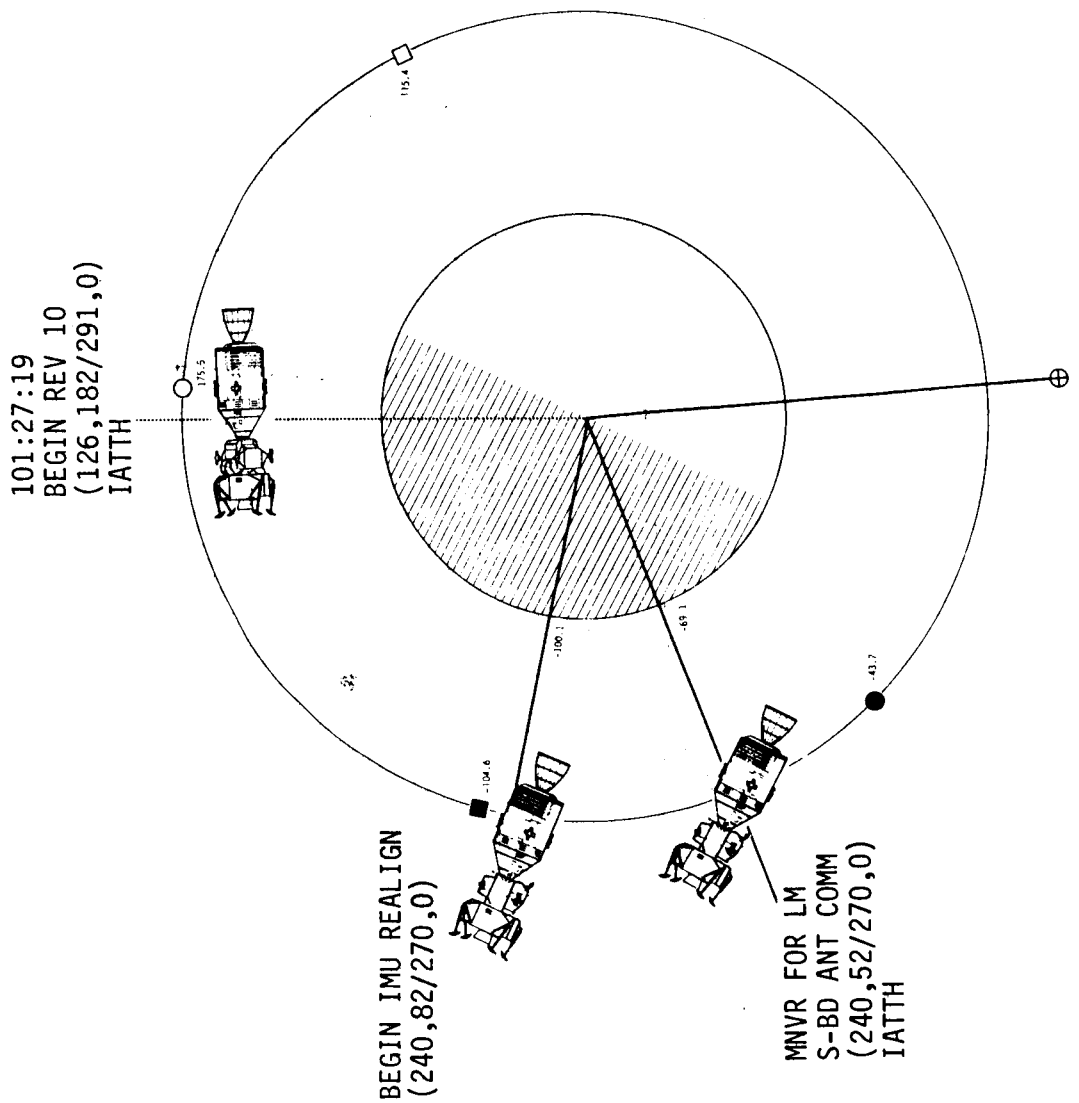


Figure 16. Tenth Revolution Major Events and Attitudes

103:25:35
 BEGIN REV 11
 (240,160/270,0)
 IATTH

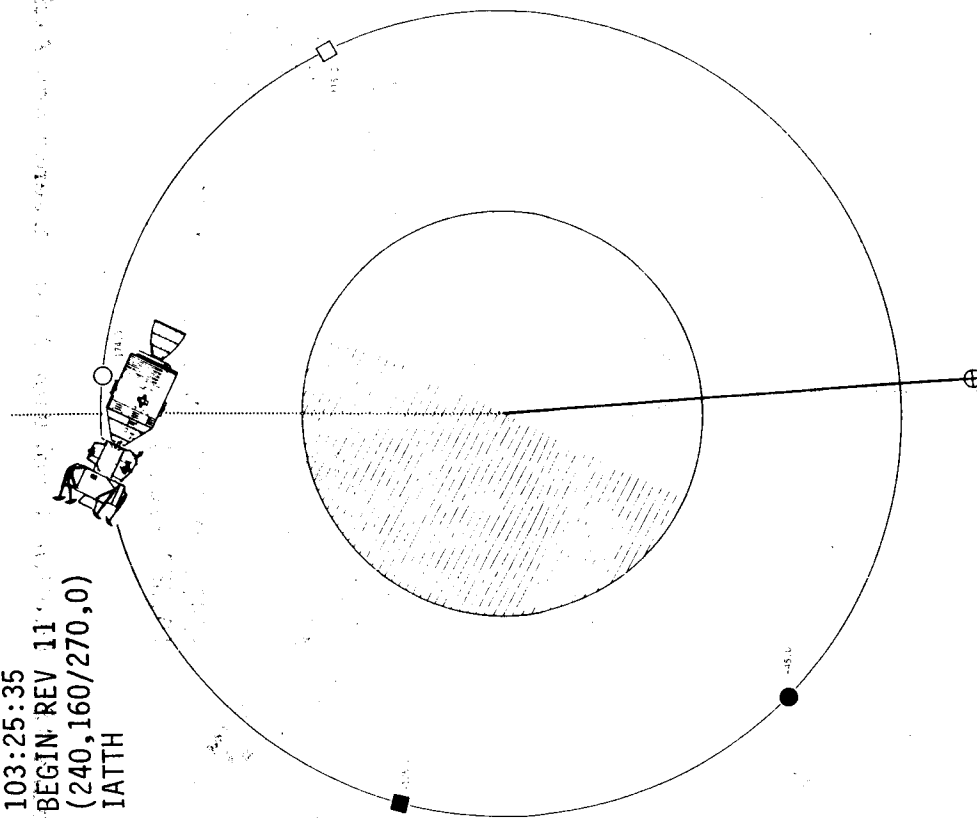


Figure 17. Eleventh Revolution Major Events and Attitudes

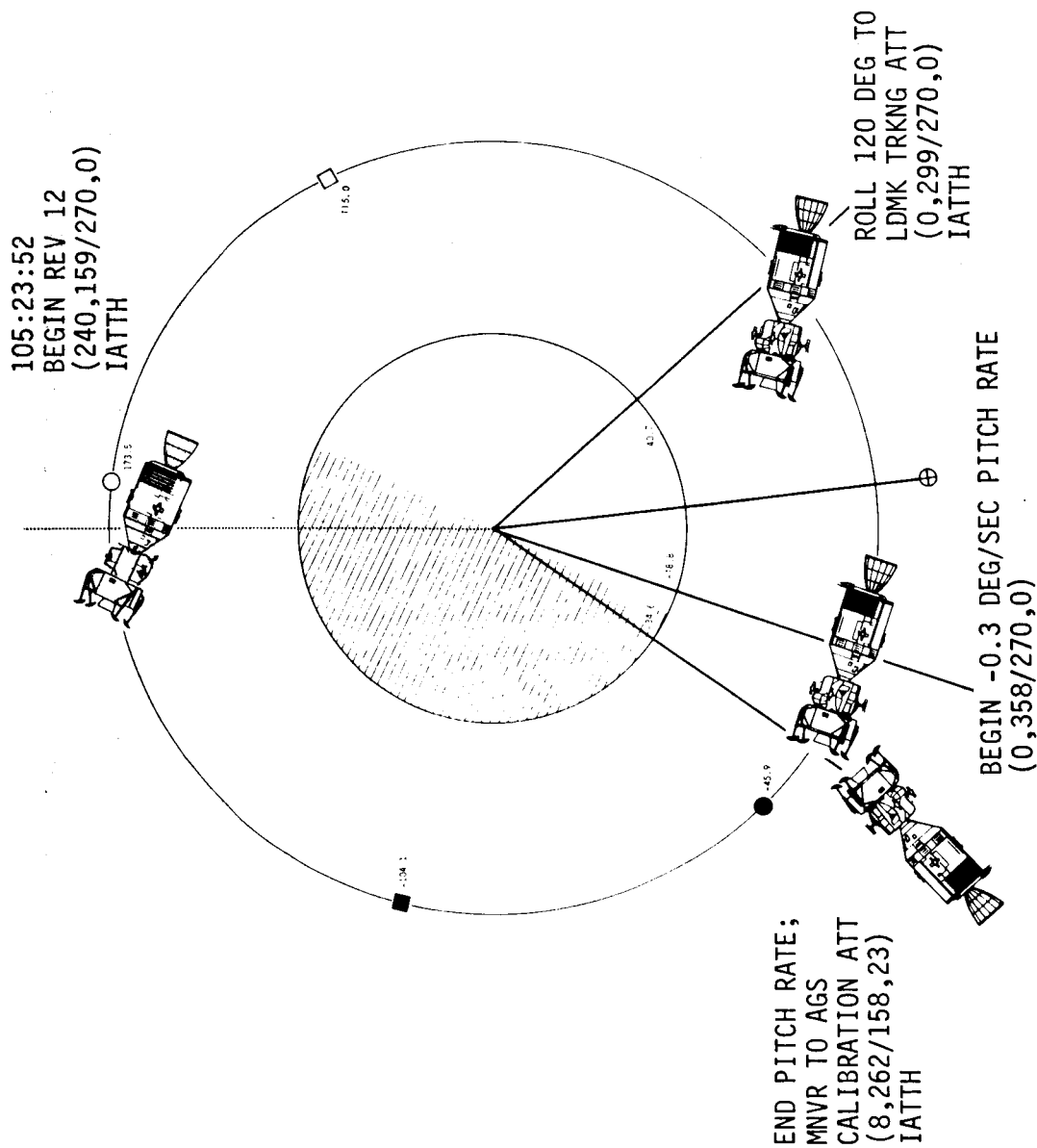


Figure 18. Twelfth Revolution Major Events and Attitudes

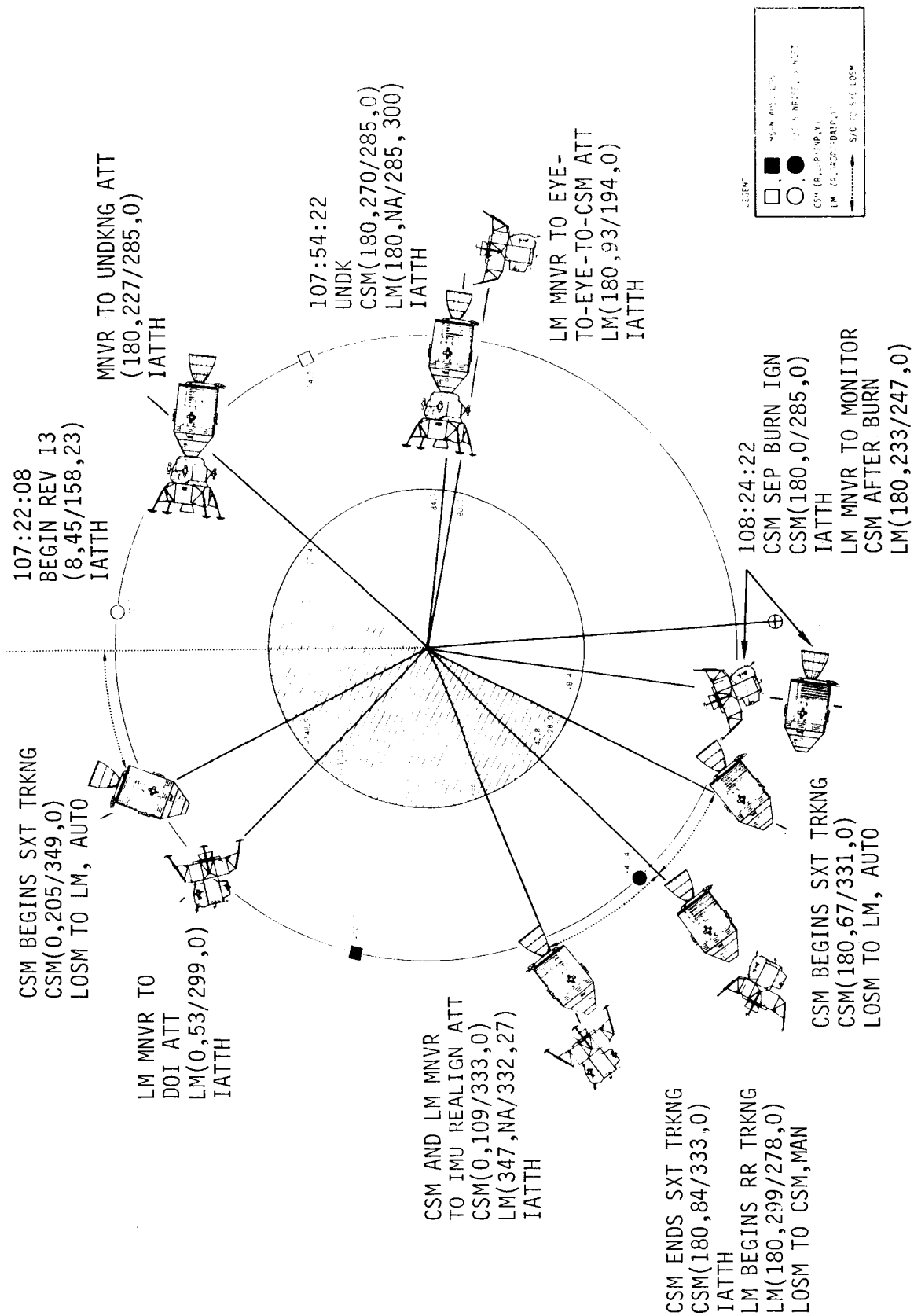


Figure 19. Thirteenth Revolution Major Events and Attitudes

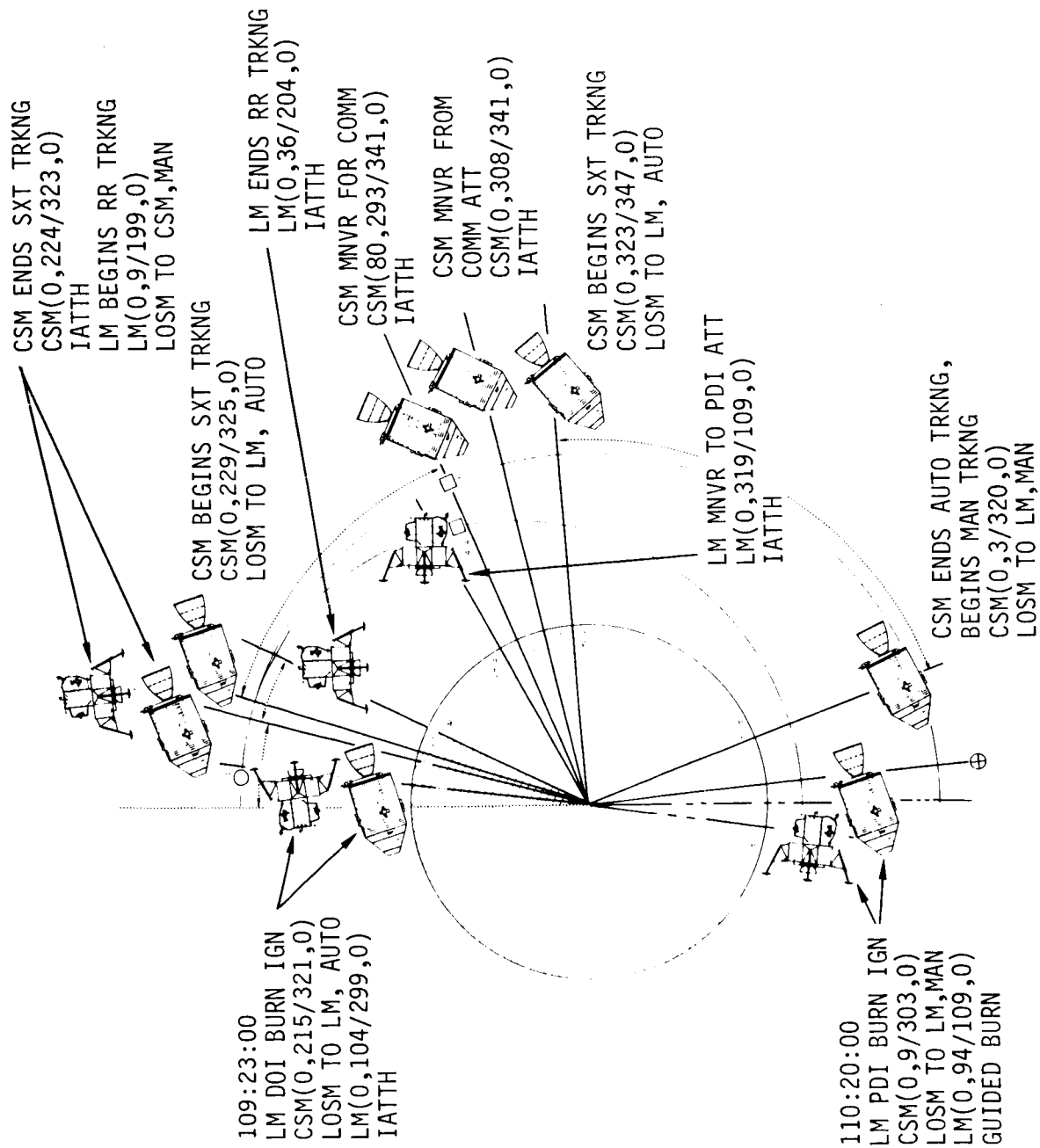


Figure 20. Fourteenth Revolution to PDI

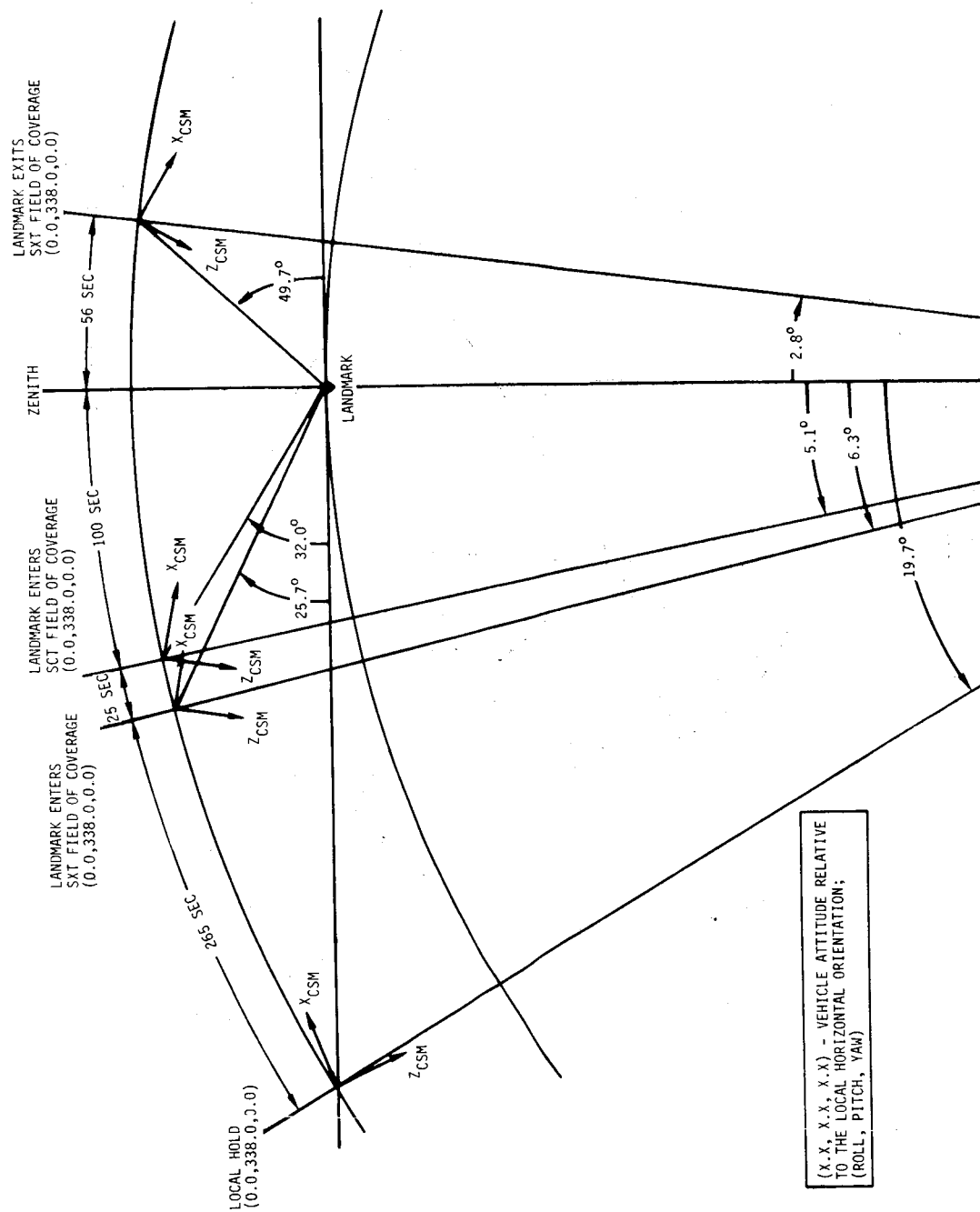


Figure 23. Tracking Geometry for Mode III Undocked Landmark Tracking

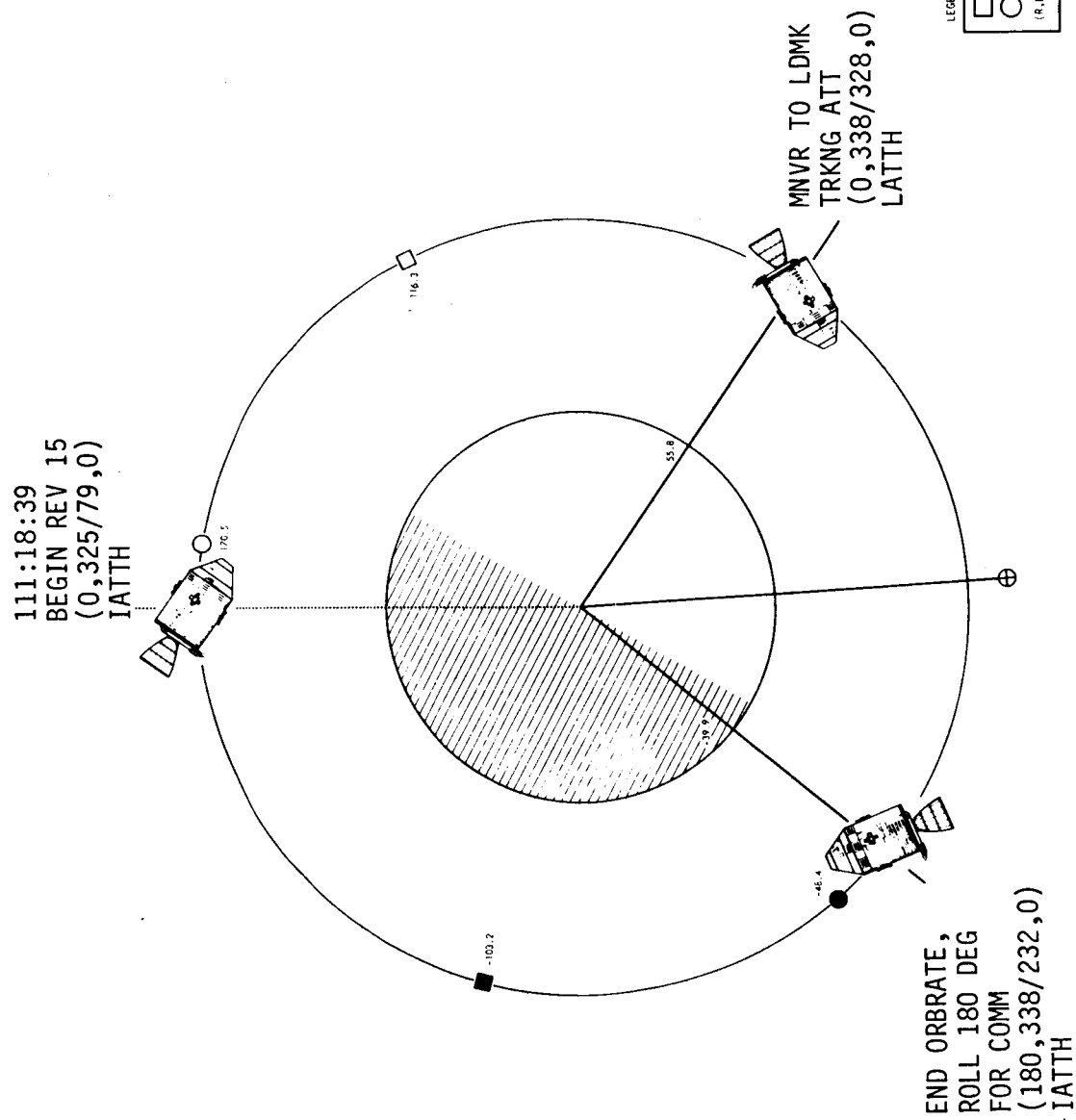


Figure 24. Fifteenth Revolution Major Events and Attitudes

113:16:56
 BEGIN REV 16
 (180,116/232,0)
 IATTH

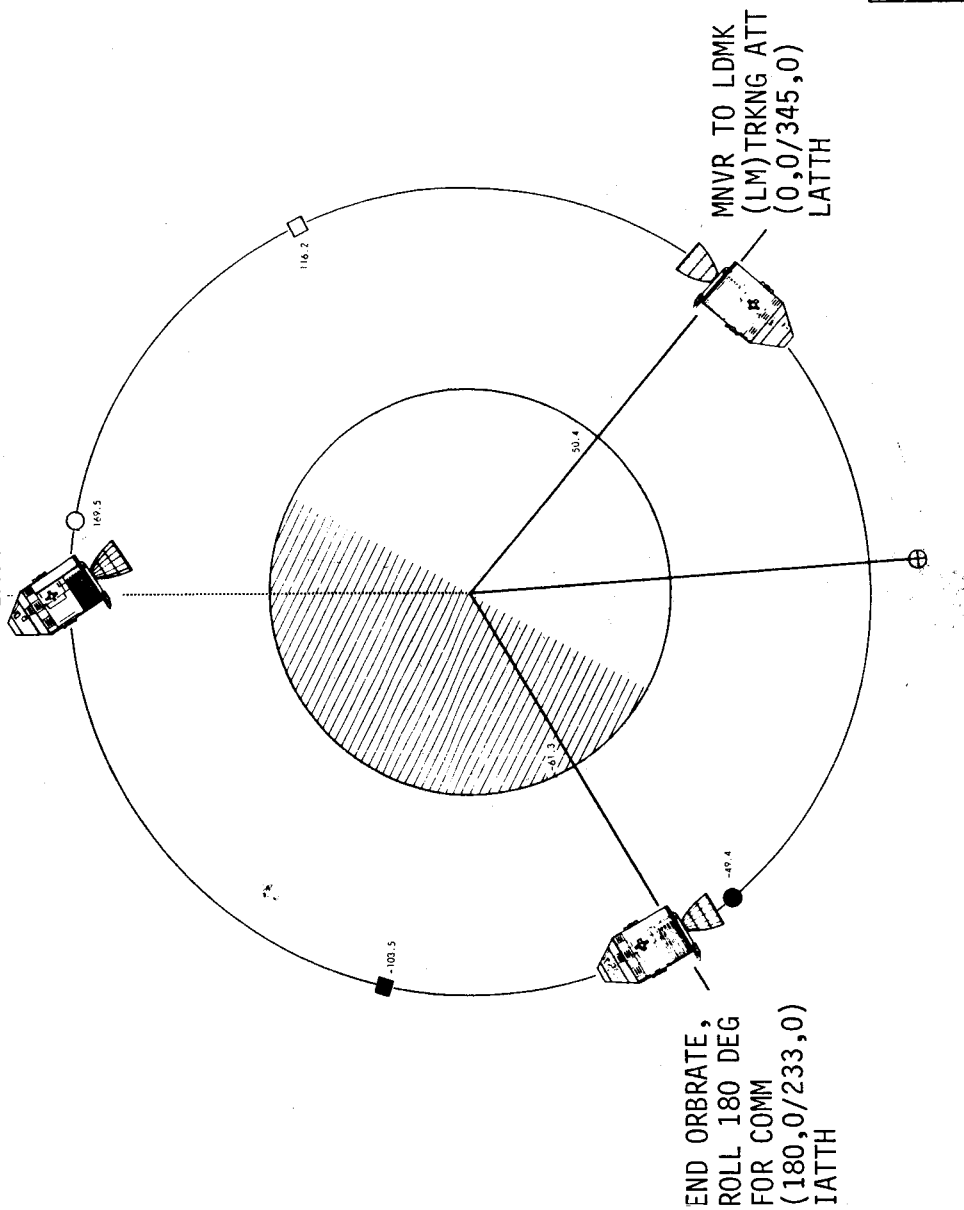


Figure 25. Sixteenth Revolution Major Events and Attitudes

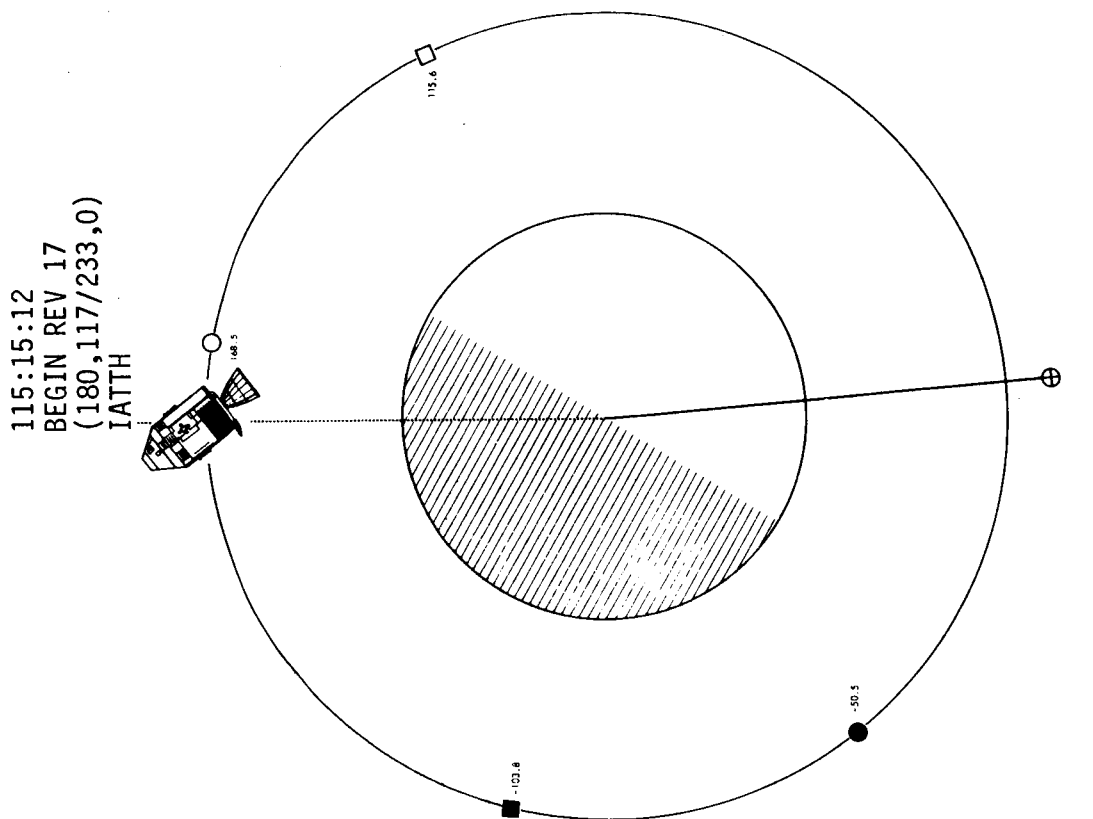


Figure 26. Seventeenth Revolution Major Events and Attitudes

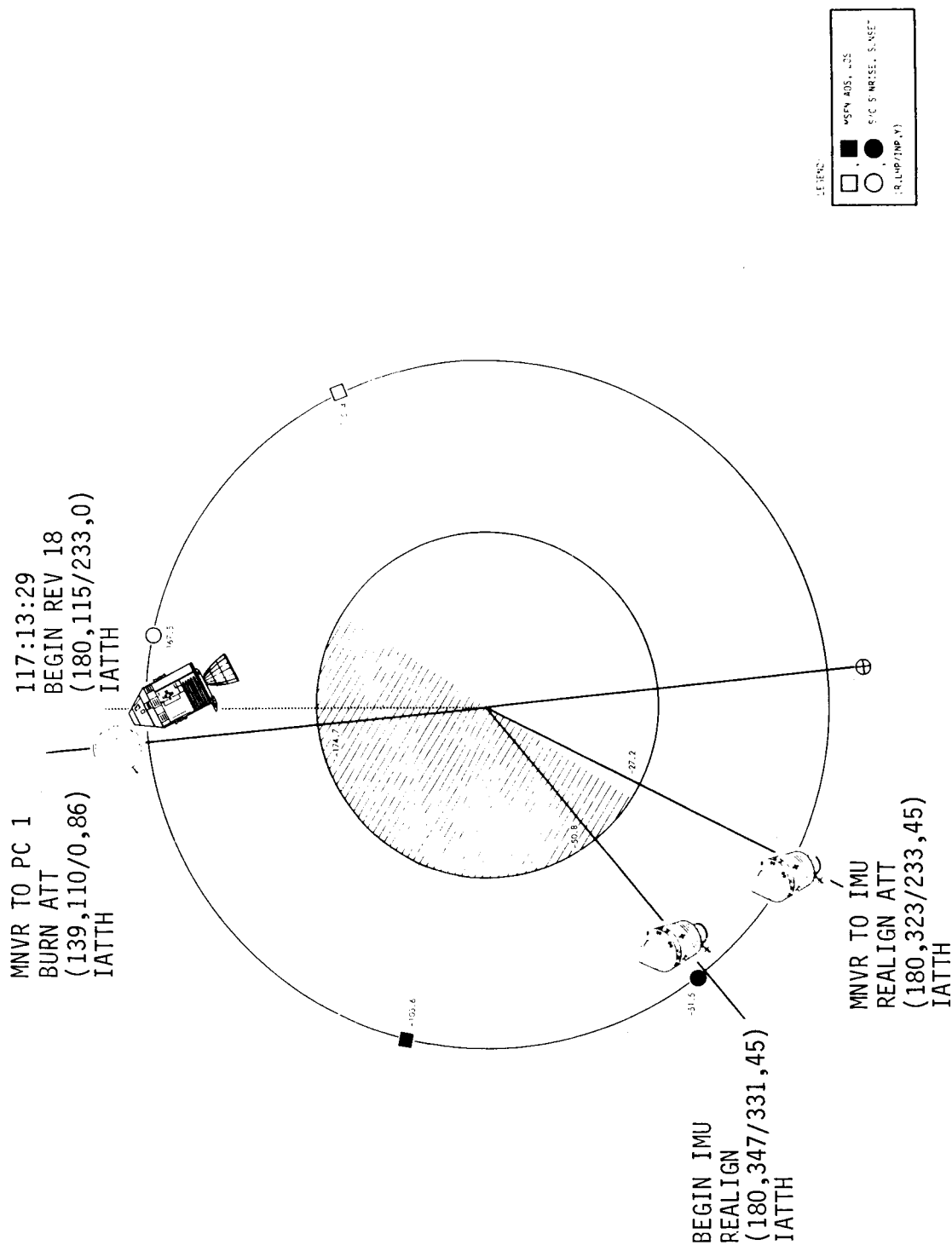


Figure 27. Eighteenth Revolution Major Events and Attitudes

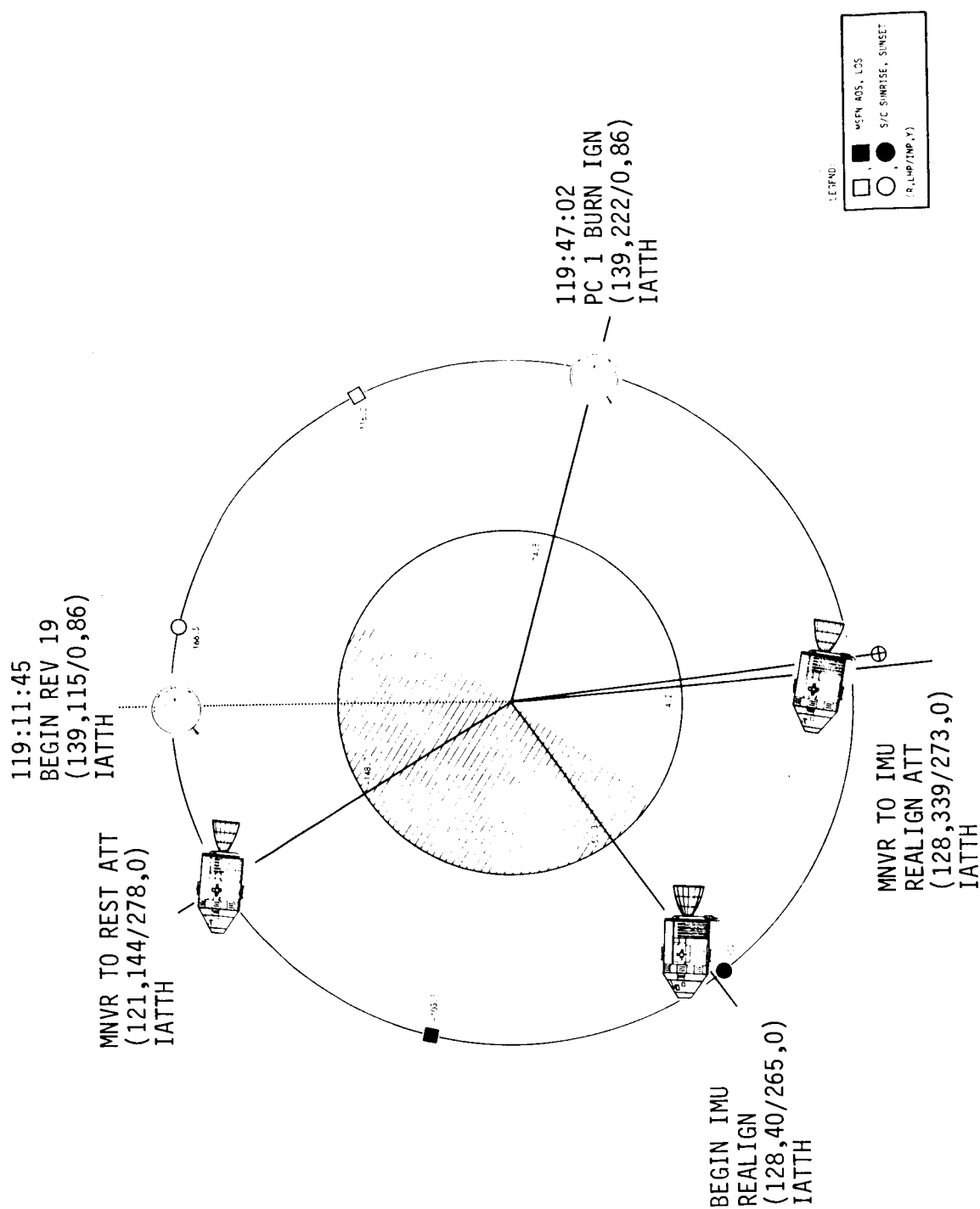
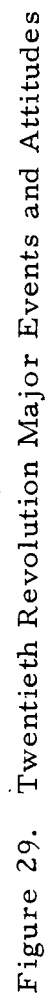


Figure 28. Nineteenth Revolution Major Events and Attitudes



123:08:35
 BEGIN REV 21
 (121,174/278,0)
 IATTH

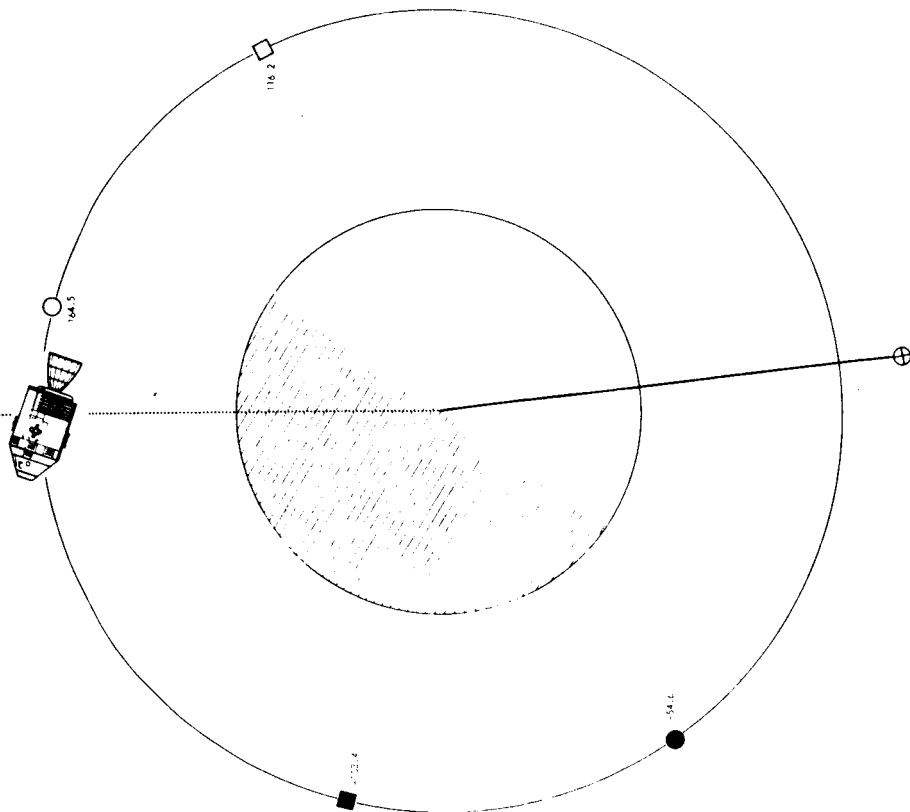
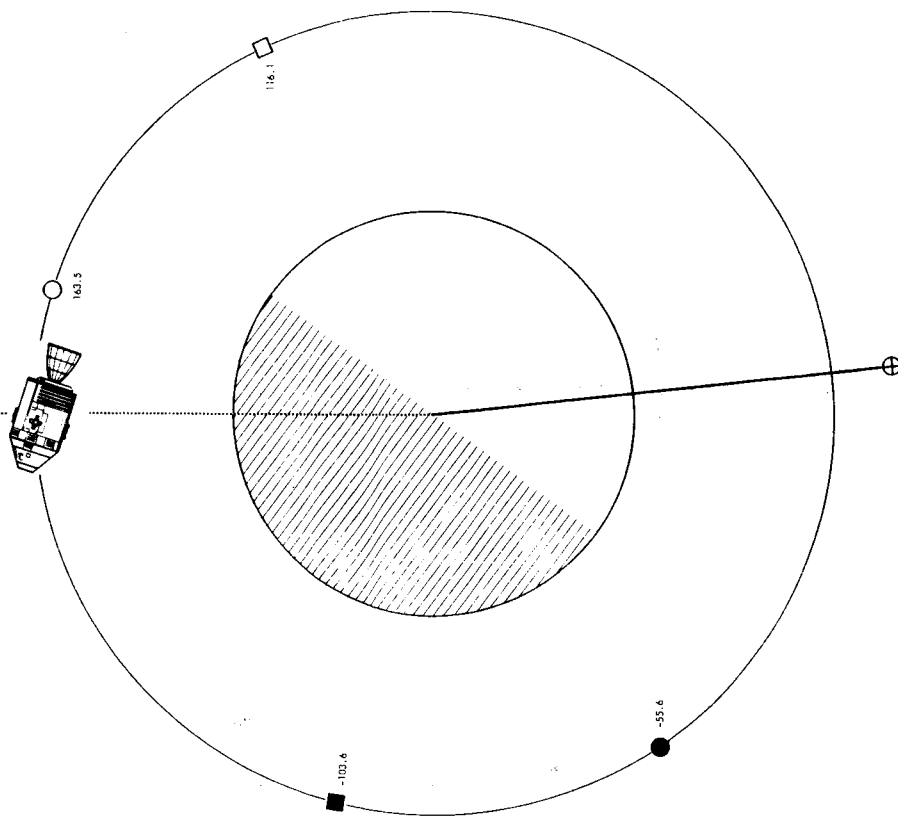


Figure 30. Twenty-first Revolution Major Events and Attitudes

125:06:51
 BEGIN REV 22
 (121,173/278,0)
 IATH



LEGEND:

■	MSFN 425, L2S
●	S/C S. NRISE, S. NRSE
□	R, L, GP, NW, Y
○	

Figure 31. Twenty-second Revolution Major Events and Attitudes

127:05:07
 BEGIN REV 23
 (121,172/278,0)
 IATTH

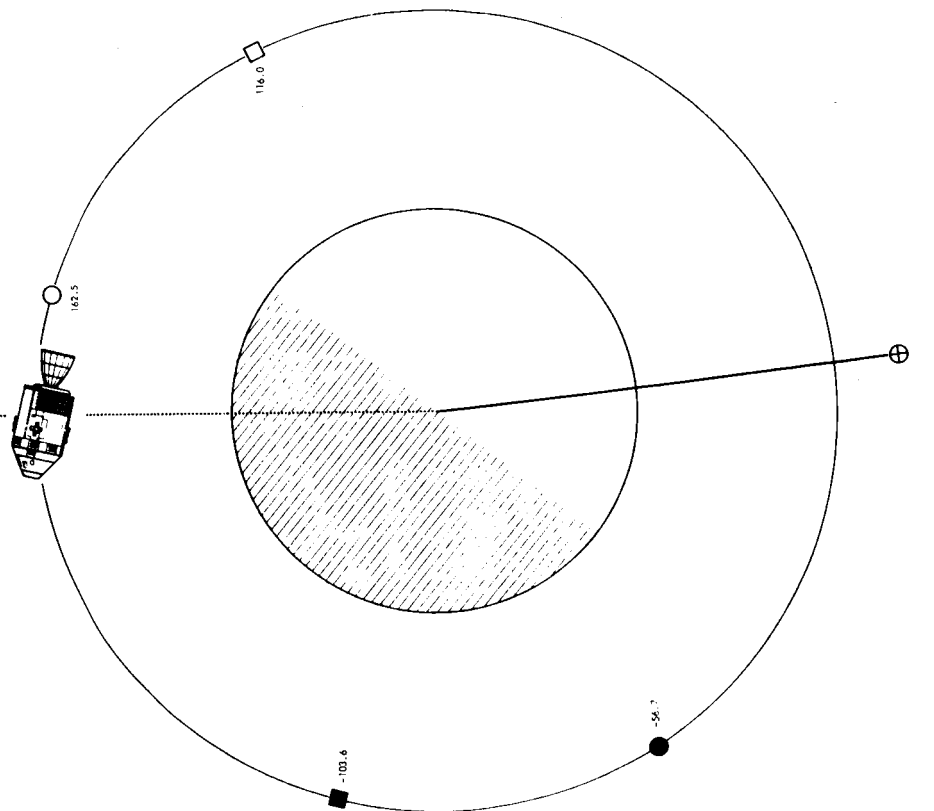
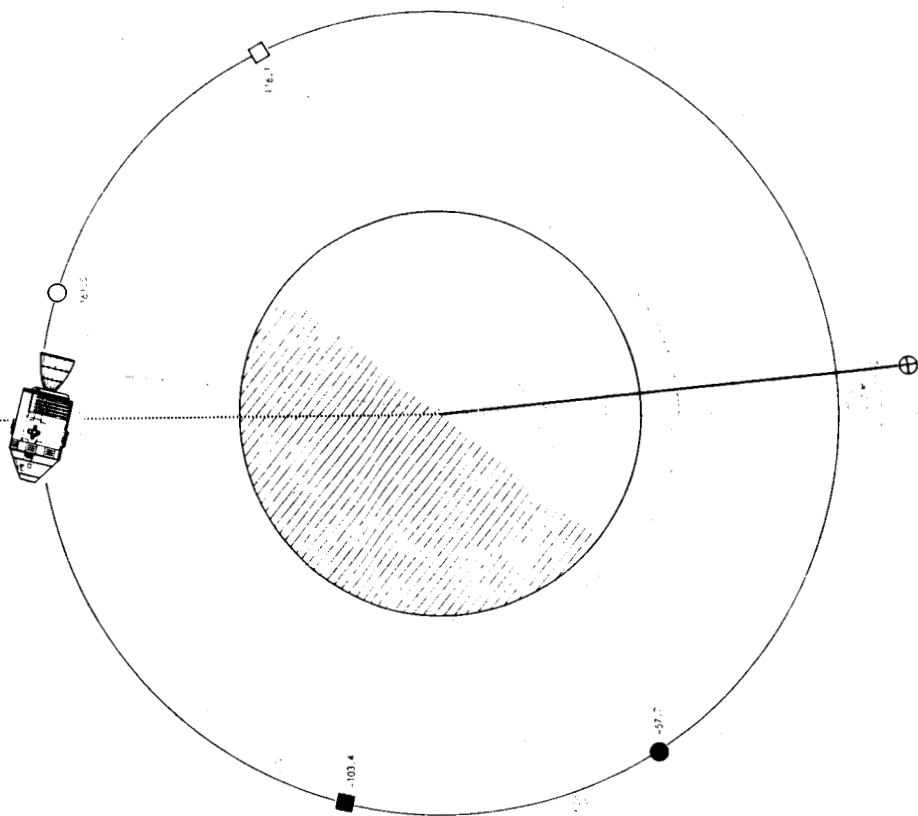


Figure 32. Twenty-third Revolution Major Events and Attitudes

129:03:24
 BEGIN REV 24
 (121,171/278,0)
 IATTH



LEGEND:

□	MSFN ADS, LOS
●	S/C SUNRISE, S. NEET
○	(R, LHP/IMP, Y)

Figure 33. Twenty-fourth Revolution Major Events and Attitudes

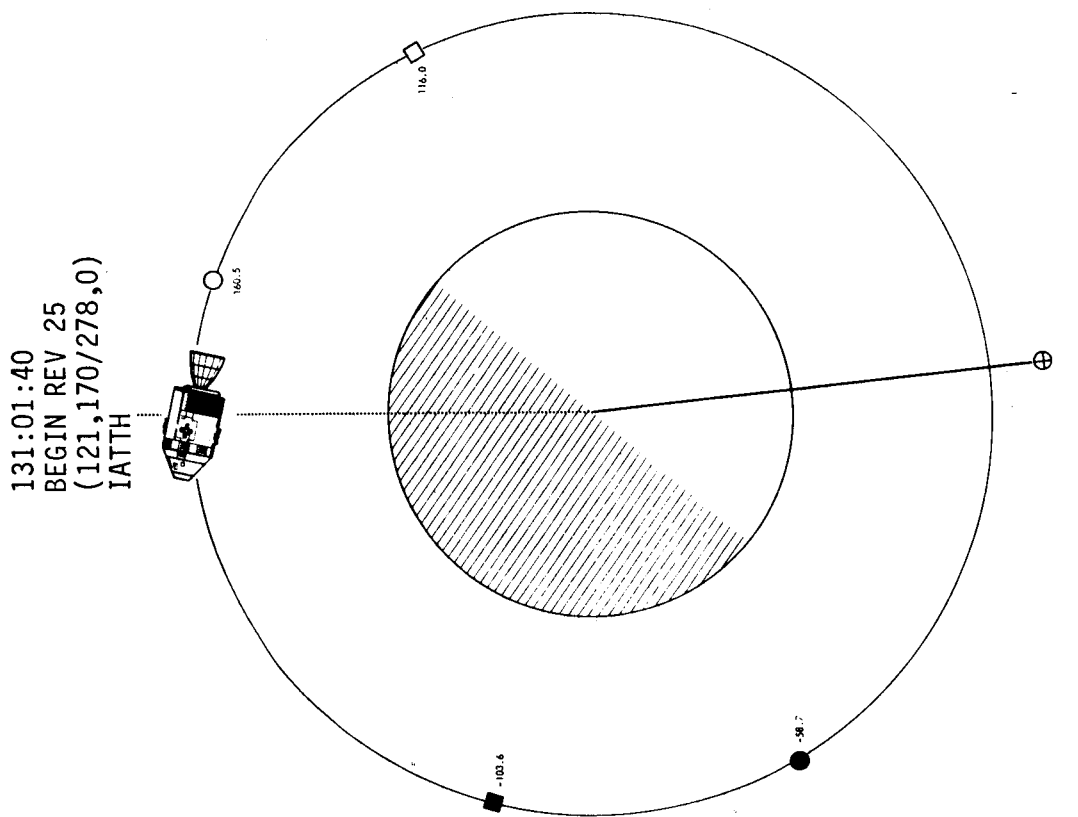


Figure 34. Twenty-fifth Revolution Major Events and Attitudes

132:59:56
 BEGIN REV 26
 (121,169/278,0)
 IATTH

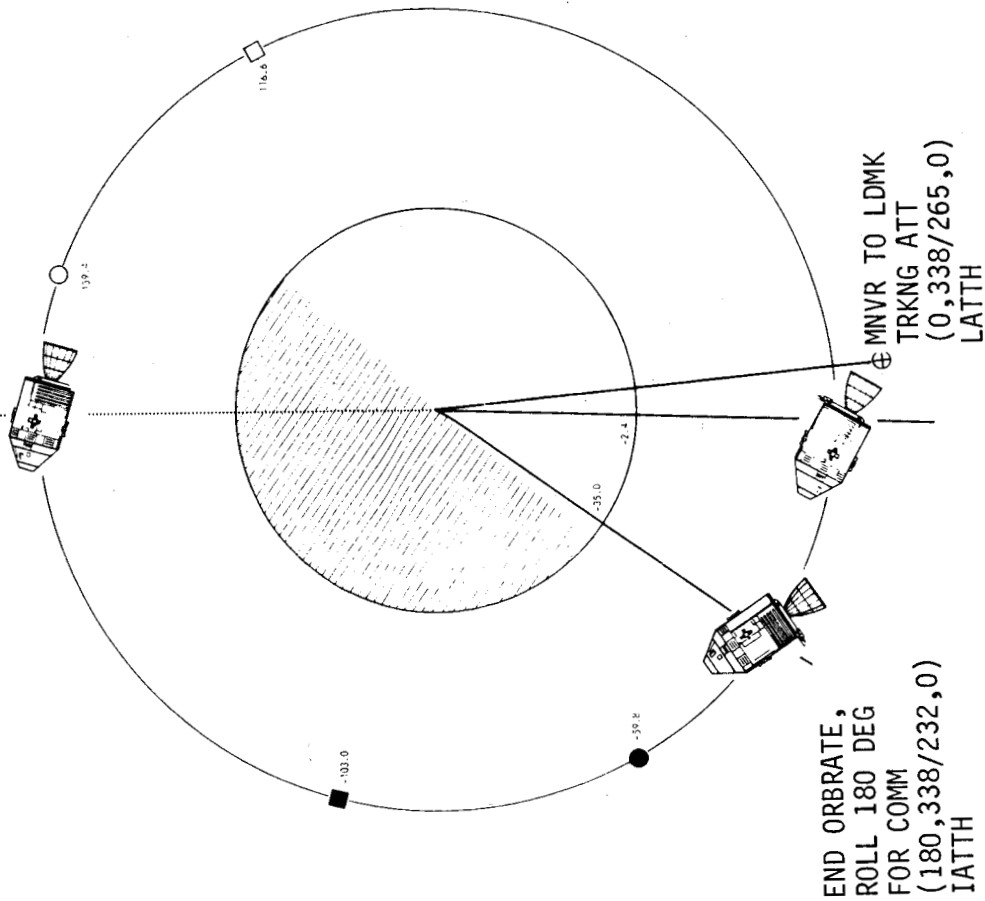
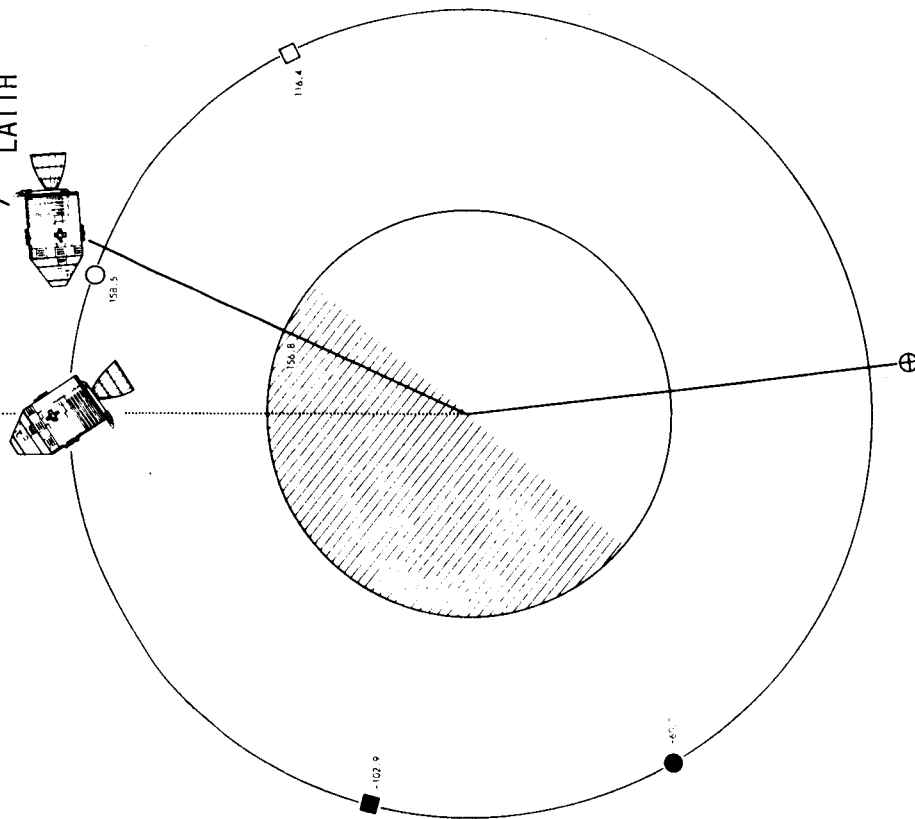


Figure 35. Twenty-sixth Revolution Major Events and Attitudes

134:58:13
 BEGIN REV 27
 (180,122/232,0)
 IATTH

MNVR TO S158
 PHOTO ATT
 (0,213/299,0)
 LATTH



LEGEND:

□	MSFN ADS, LOS
○	S/C SUNRISE, SUNSET
●	(R, LHP/IMP, Y)

Figure 36. Twenty-seventh Revolution Major Events and Attitudes

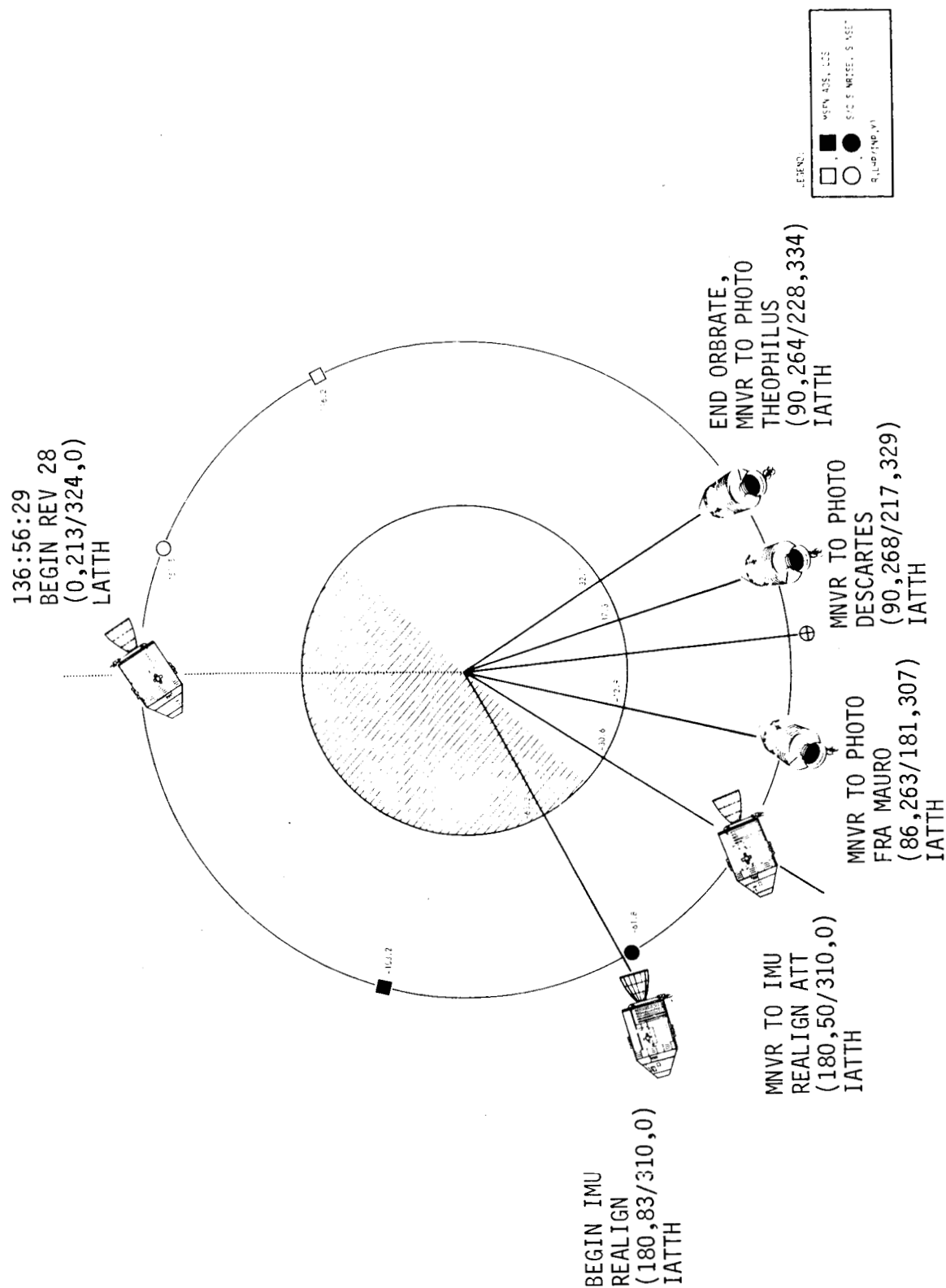


Figure 37. Twenty-eight Revolution Major Events and Attitudes

138:54:46
 BEGIN REV 29
 (180,198/310,0)
 IATTH

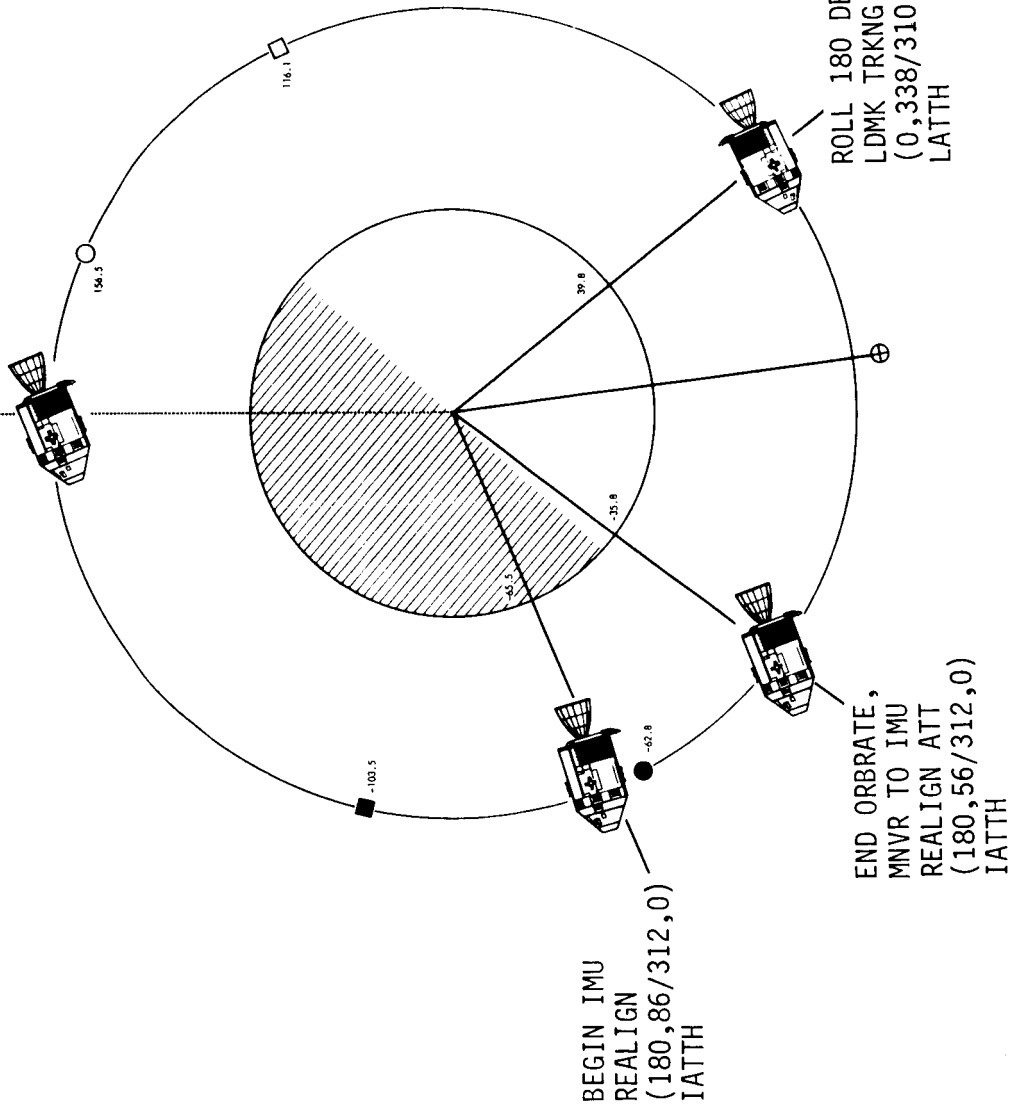


Figure 38. Twenty-ninth Revolution Major Events and Attitudes

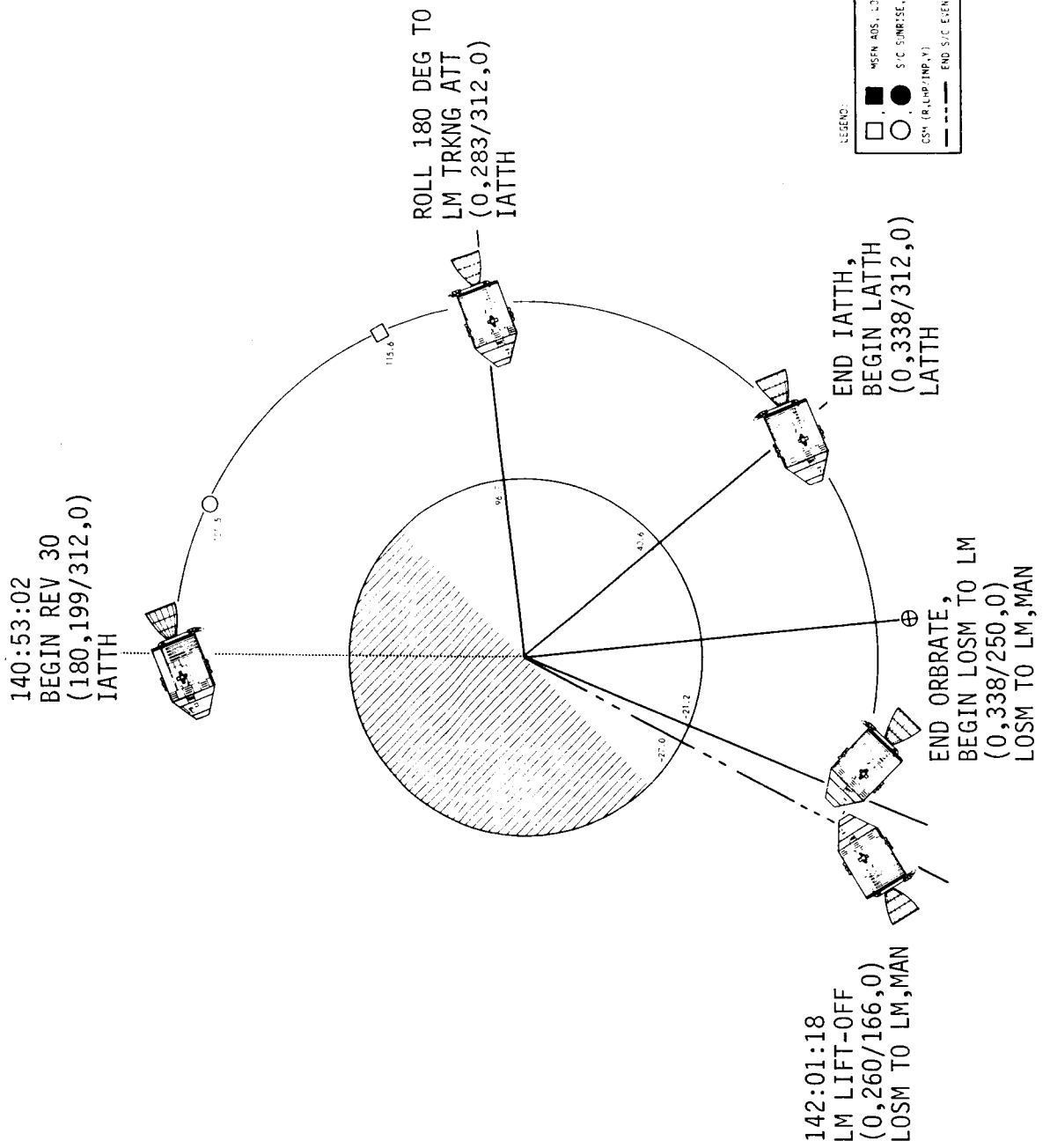


Figure 39. Thirtieth Revolution to LM Lift-off

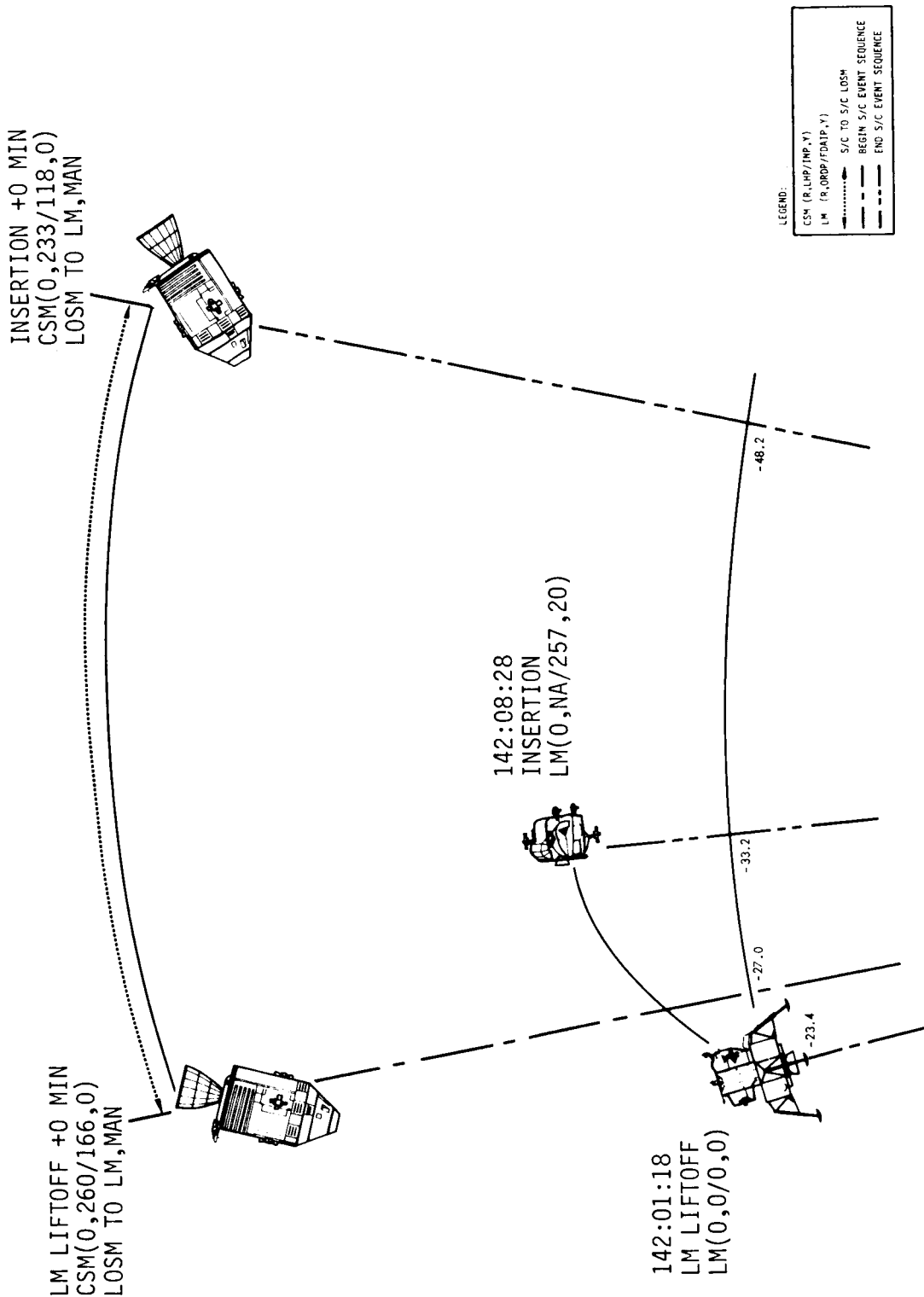


Figure 40. LM Lift-off to Insertion Burn Cutoff

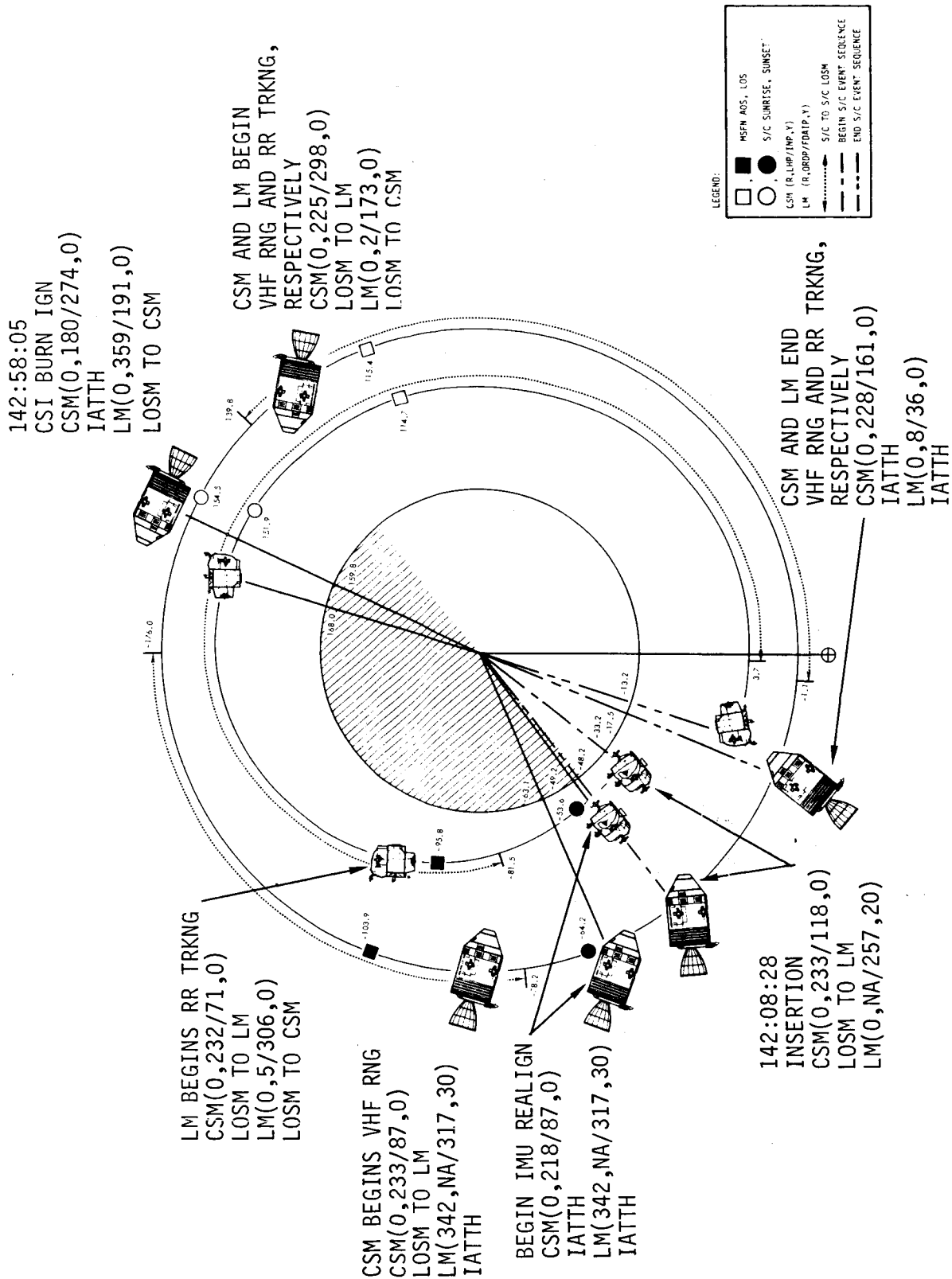


Figure 41. Insertion Burn Cutoff to Tracking Termination Prior to CDH

144:36:50
TPI BURN IGN
CSM(0,209/4,0)
IATTH
LM(0,18/273,0)
LOSM TO CSM

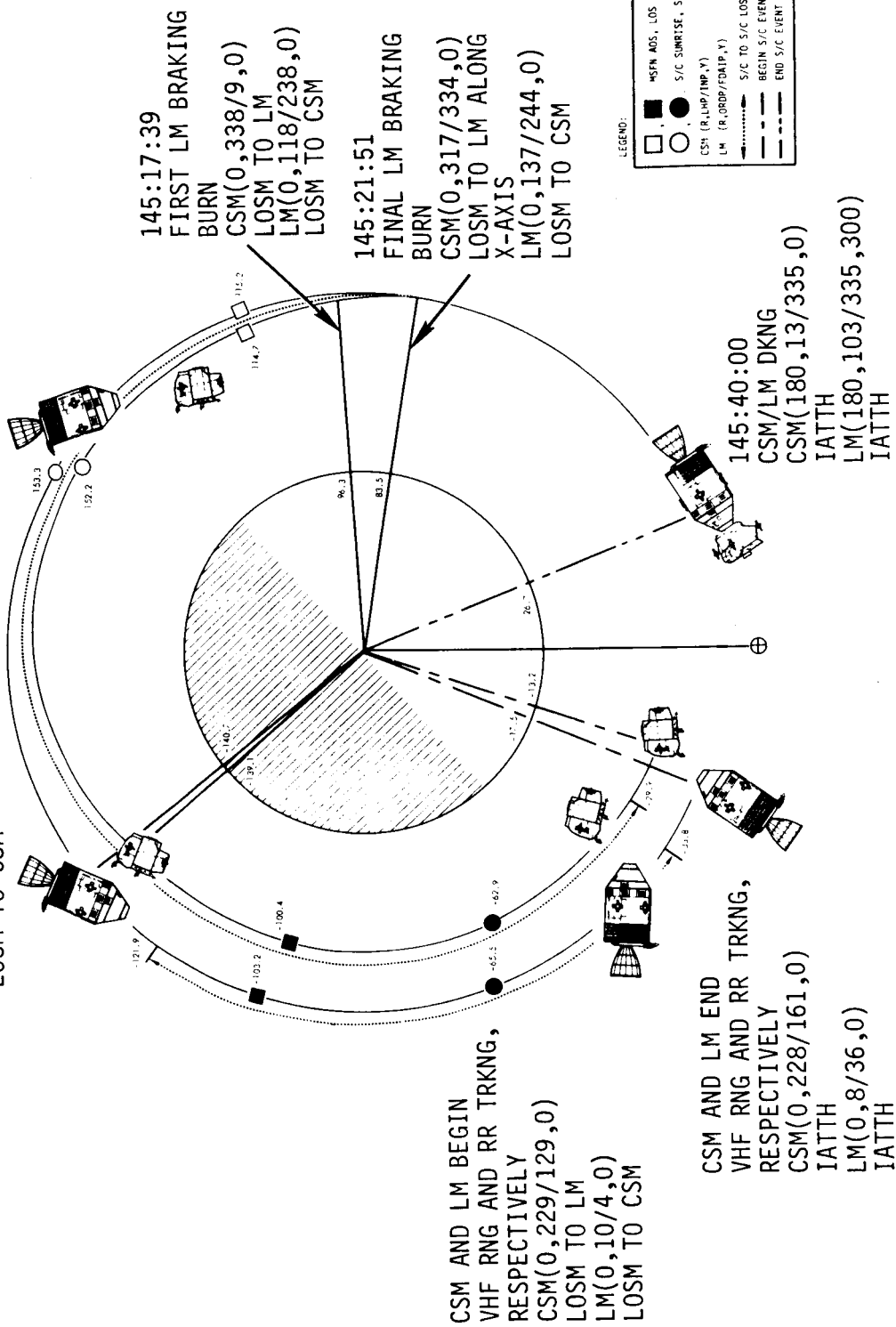


Figure 42. Tracking Termination Prior to CDH CSM/LM Docking

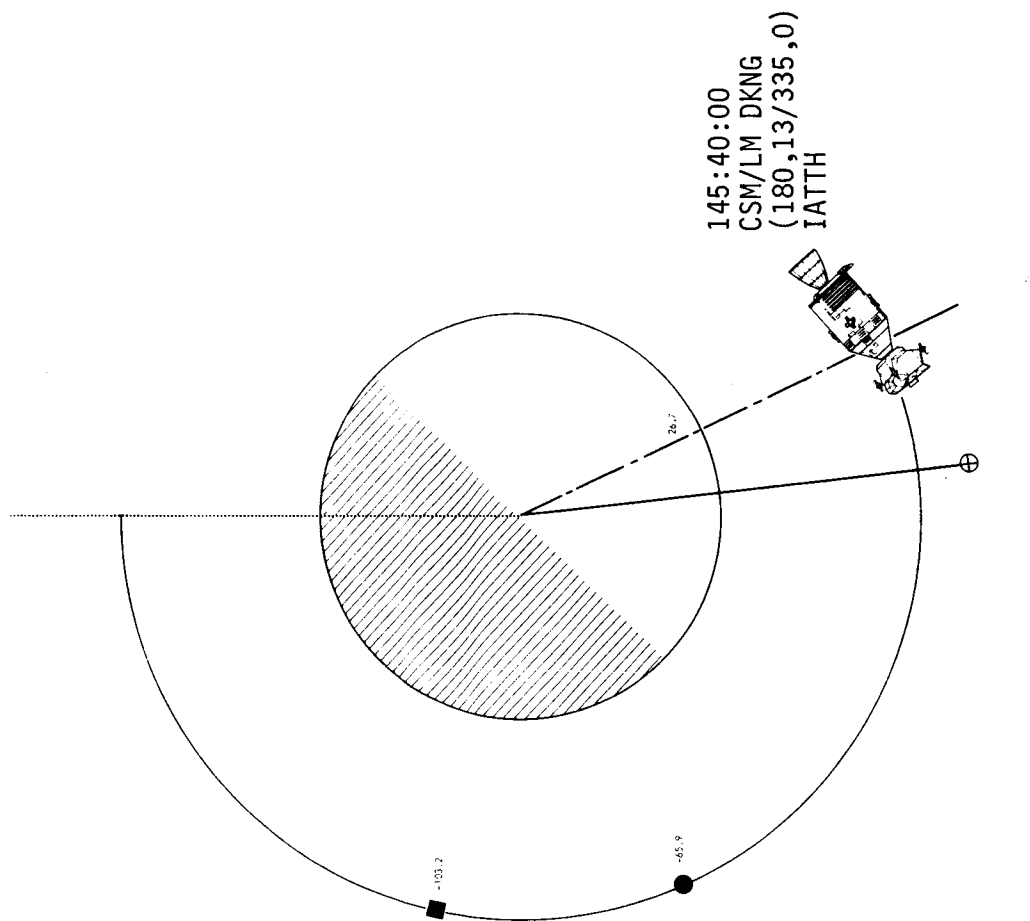


Figure 43. CSM/LM Docking to Completion of Thirty-second Revolution

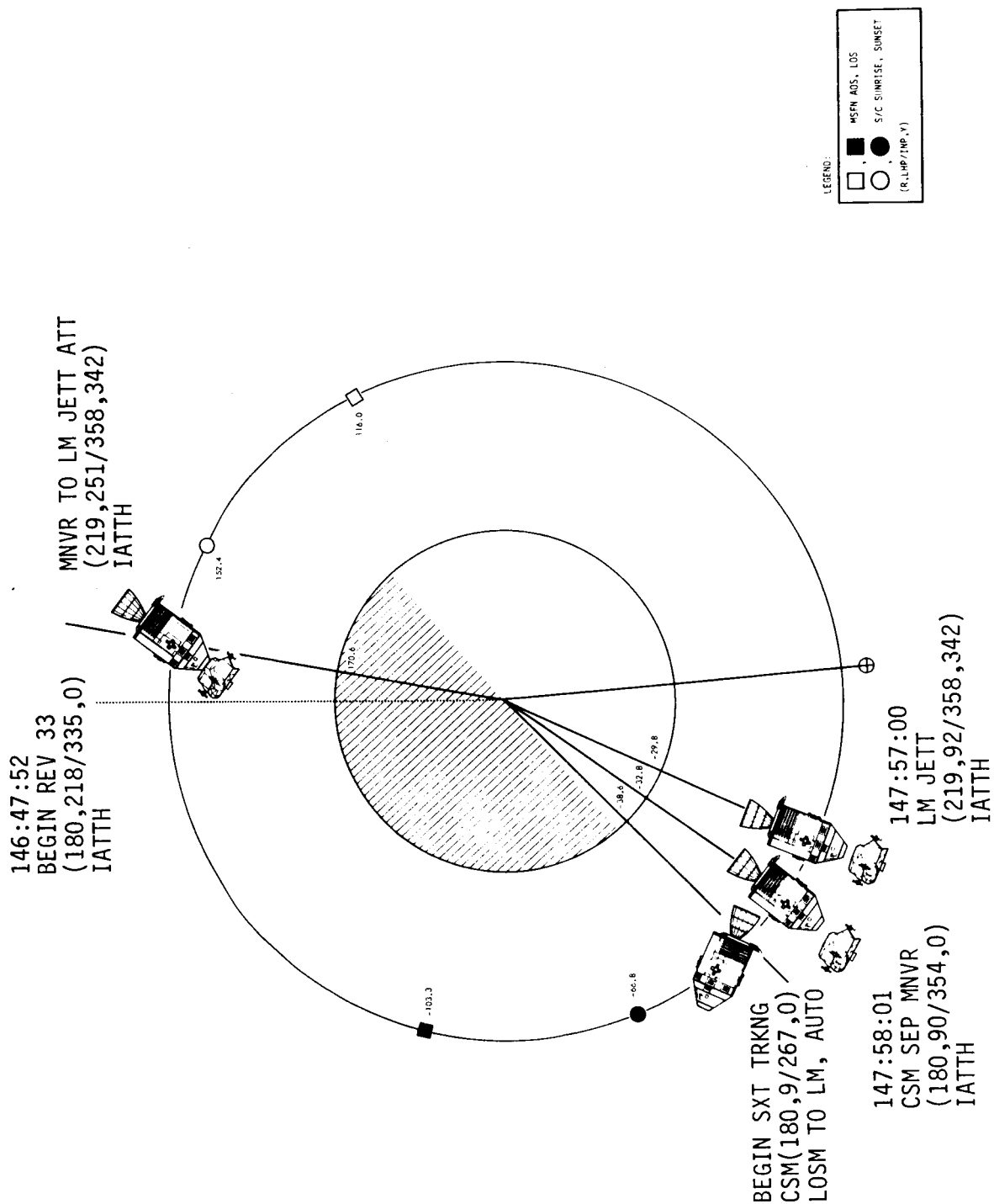


Figure 44. Thirty-third Revolution Major Events and Attitudes

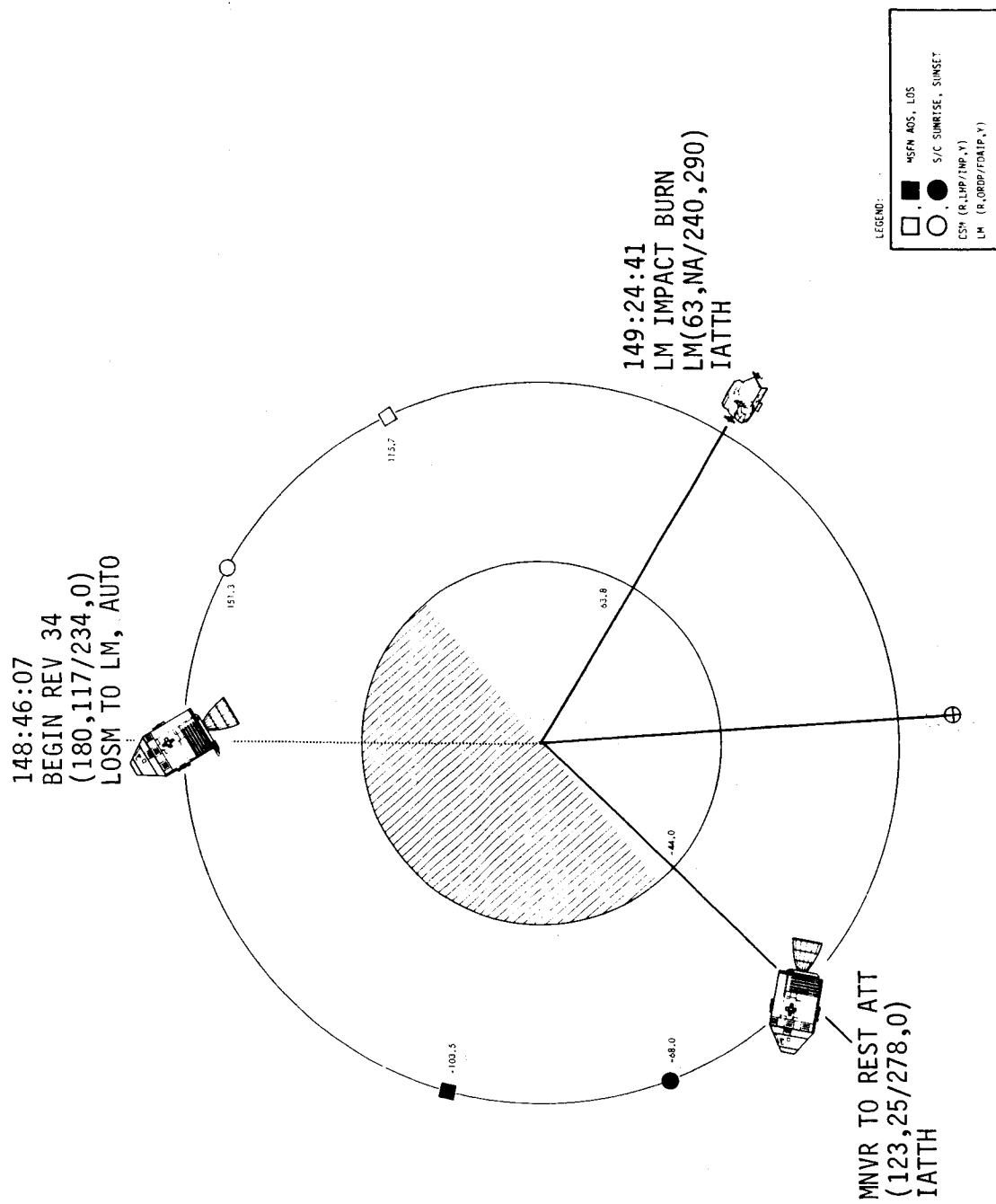


Figure 45. Thirty-fourth Revolution Major Events and Attitudes

150:44:20
 BEGIN REV 35
 (123,159/278,0)
 IATTH

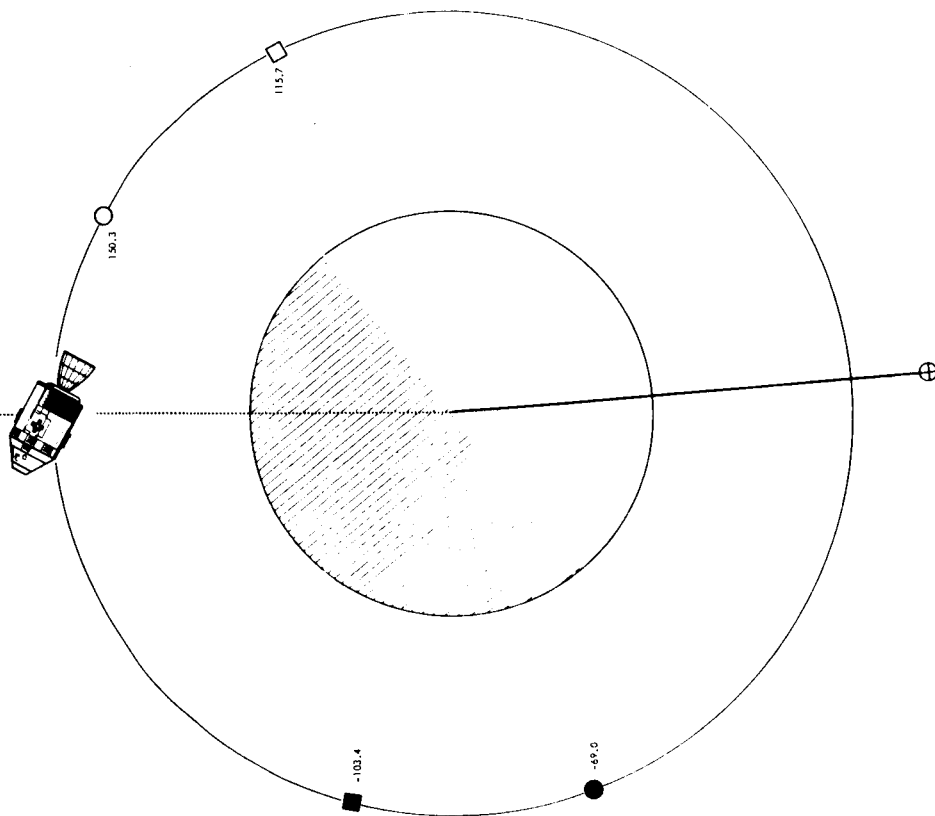
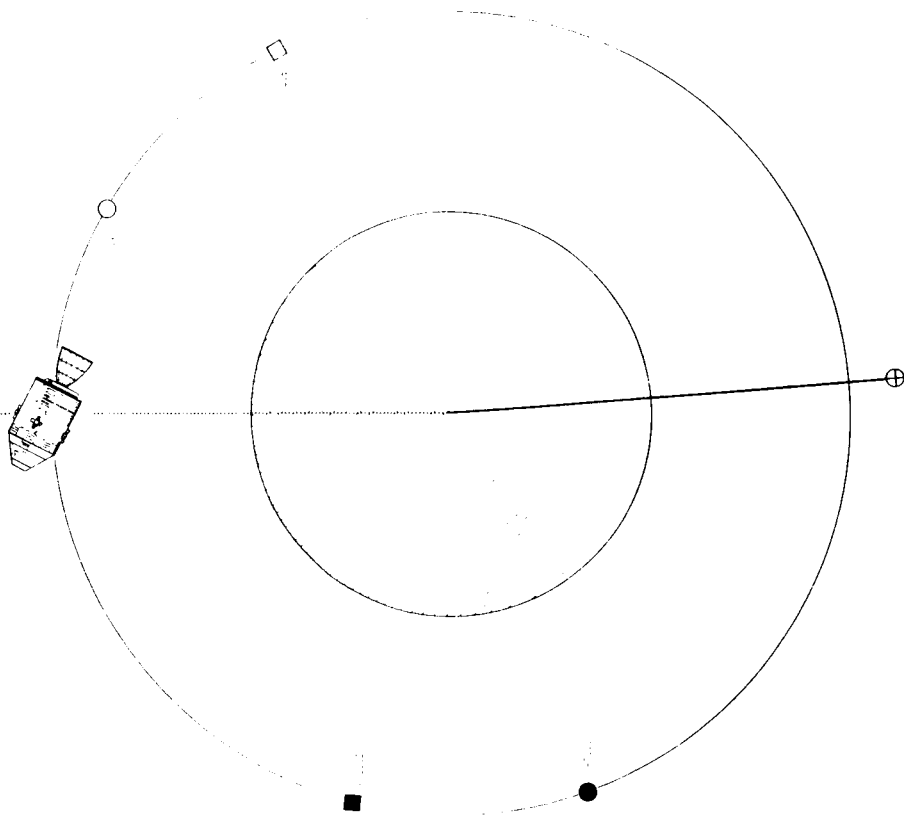


Figure 46. Thirty-fifth Revolution Major Events and Attitudes

152:42:33
 BEGIN REV 36
 (123,158/278,0)
 IATH



LEGEND:
 □ WSE, ANS, L2E
 ○ WSE, ANS, L2E
 ■ R10 I MUSE, L5, ANS
 ● R10 I MUSE, L5, ANS

Figure 47. Thirty-sixth Revolution Major Events and Attitudes

154:40:45
 BEGIN REV 37
 (123,157/278,0)
 IATTH

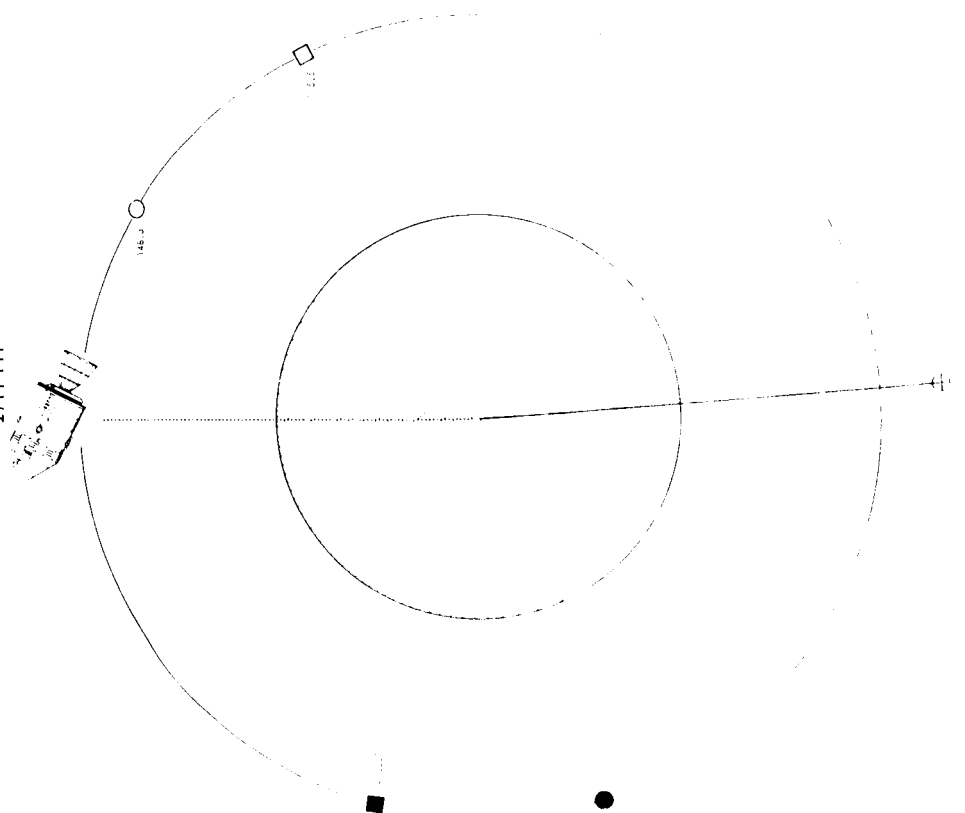


Figure 48. Thirty-seventh Revolution Major Events and Attitudes

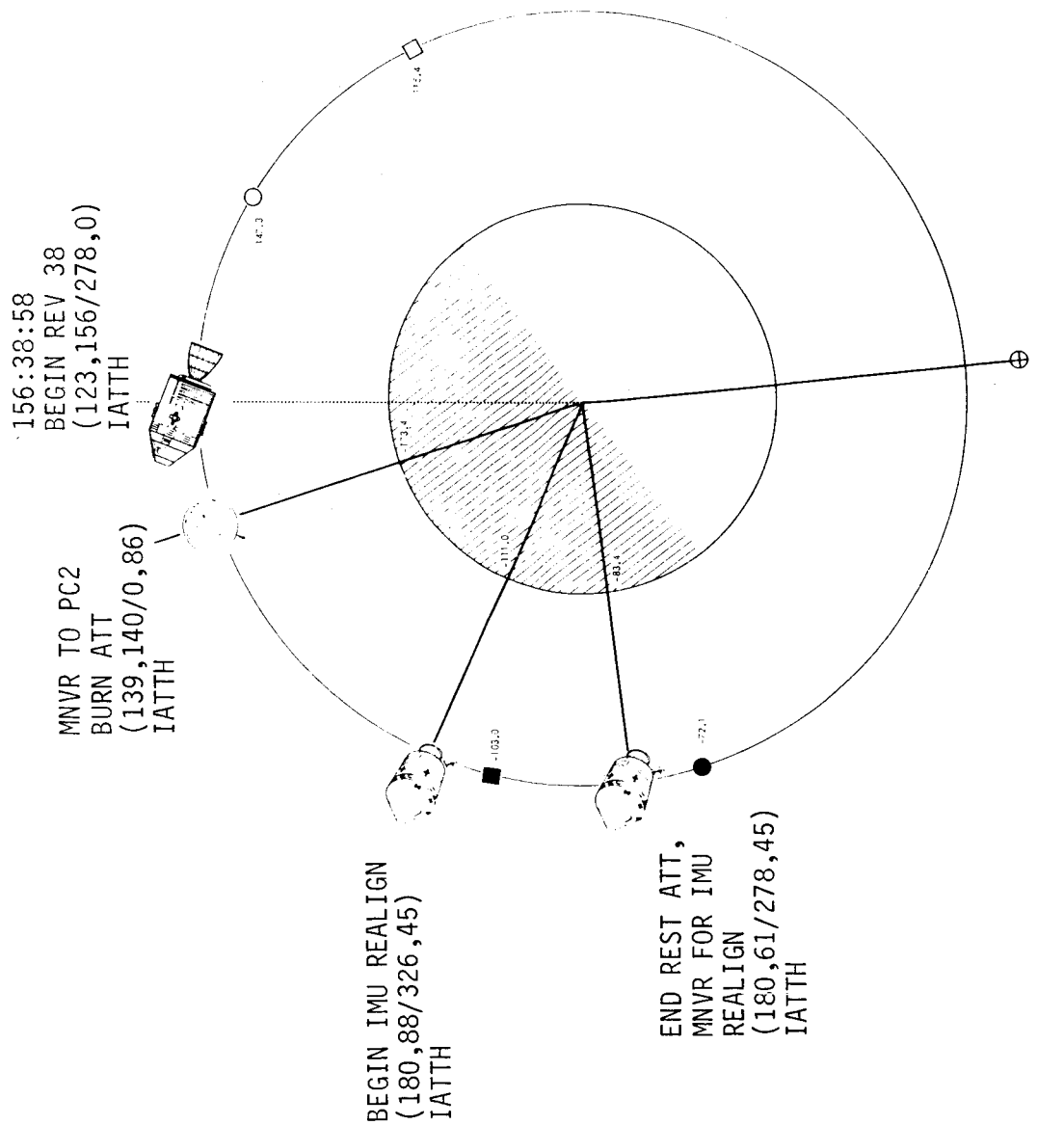


Figure 49. Thirty-eight Revolution Major Events and Attitudes

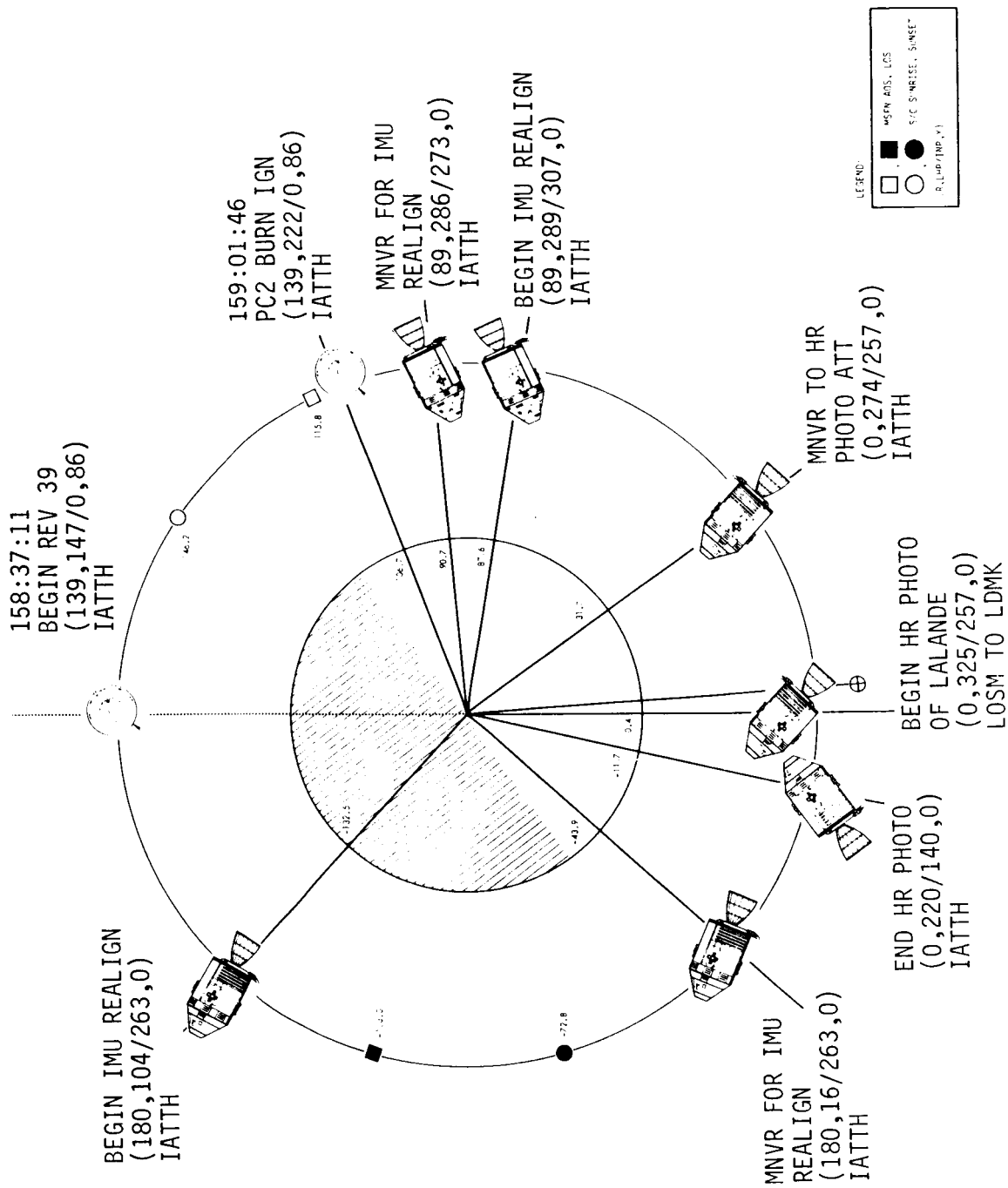


Figure 50. Thirty-ninth Revolution Major Events and Attitudes

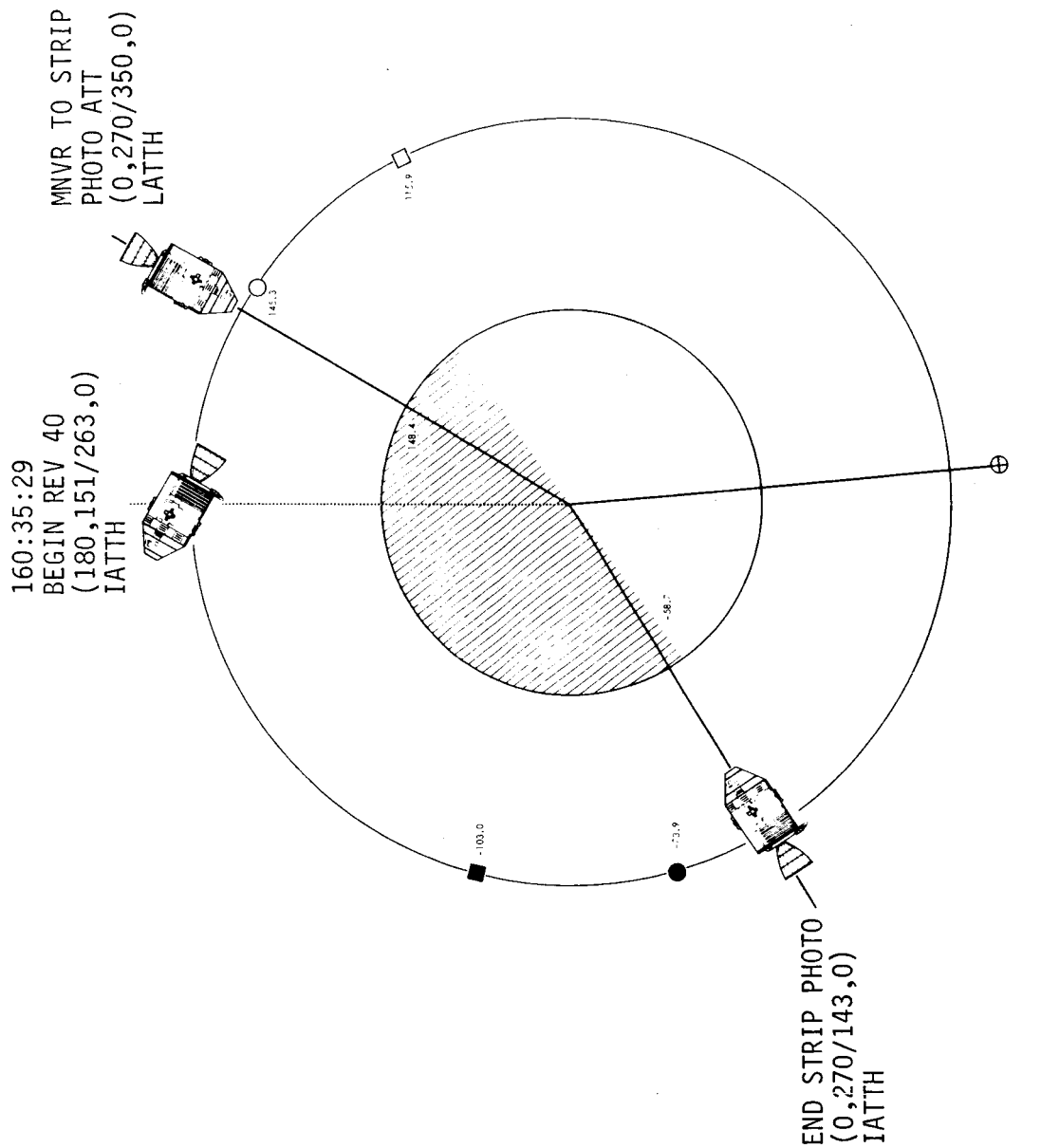


Figure 51. Fortieth Revolution Major Events and Attitudes

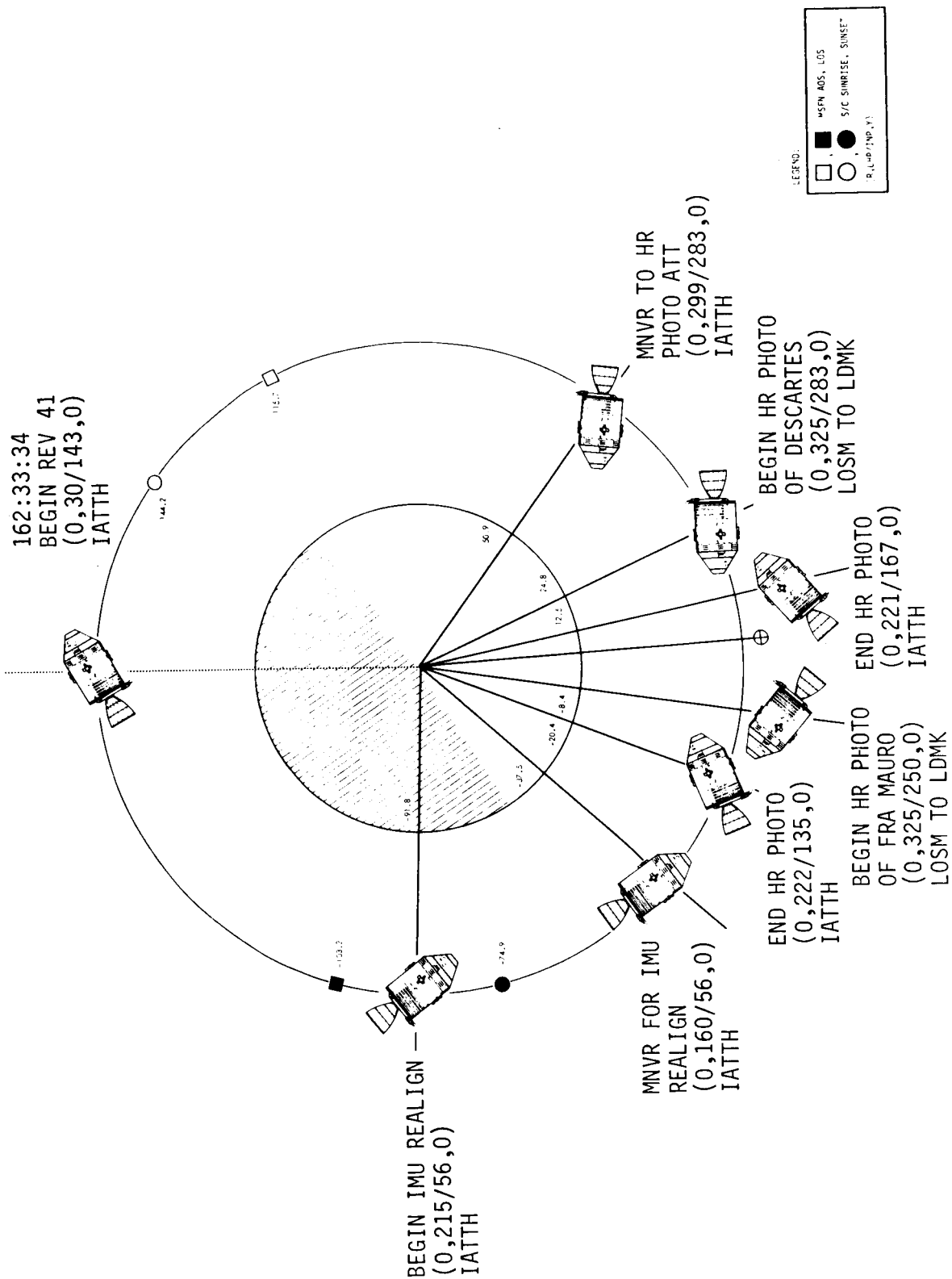


Figure 52. Forty-first Revolution Major Events and Attitudes

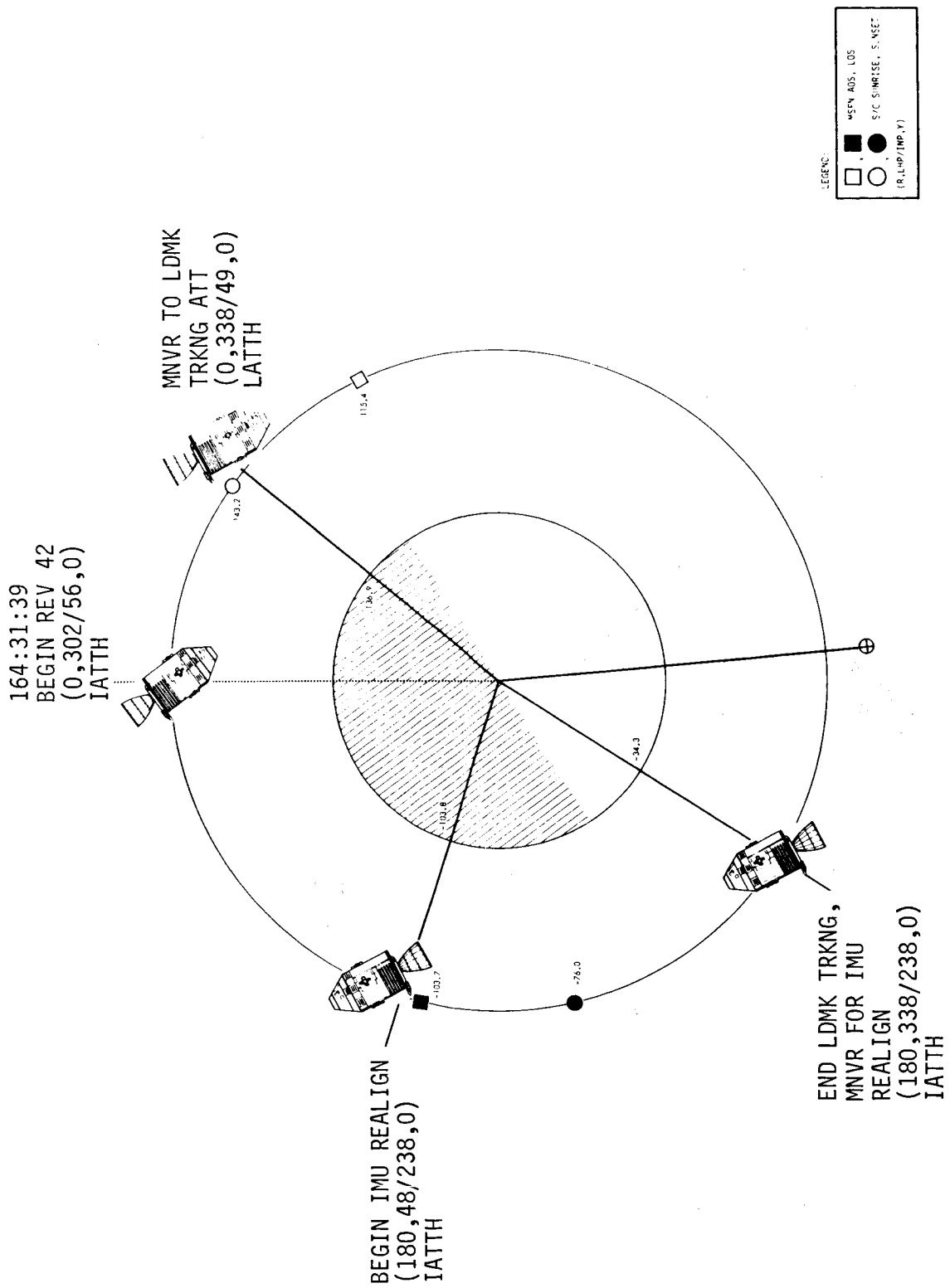


Figure 53. Forty-second Revolution Major Events and Attitudes

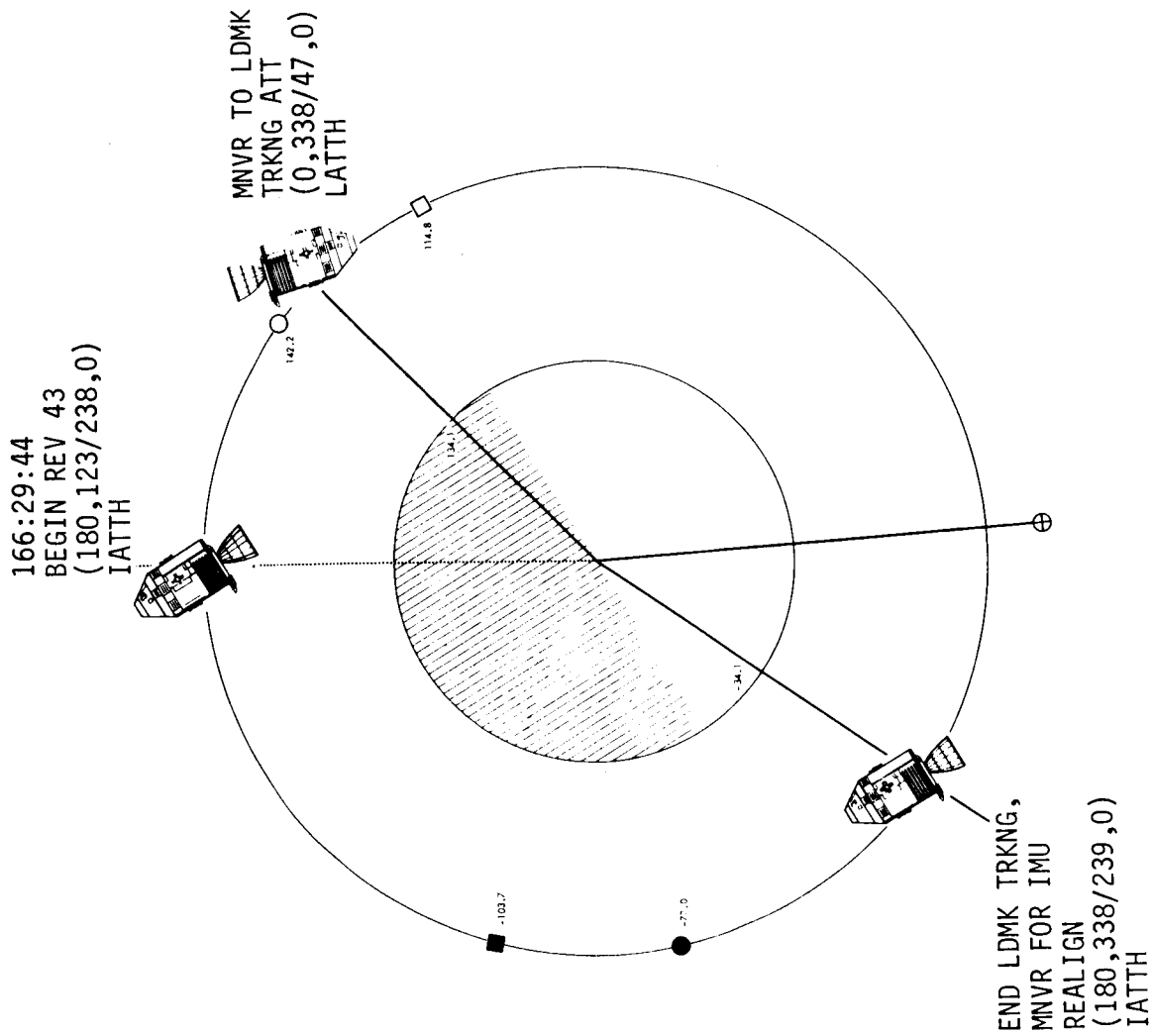


Figure 54. Forty-third Revolution Major Events and Attitudes

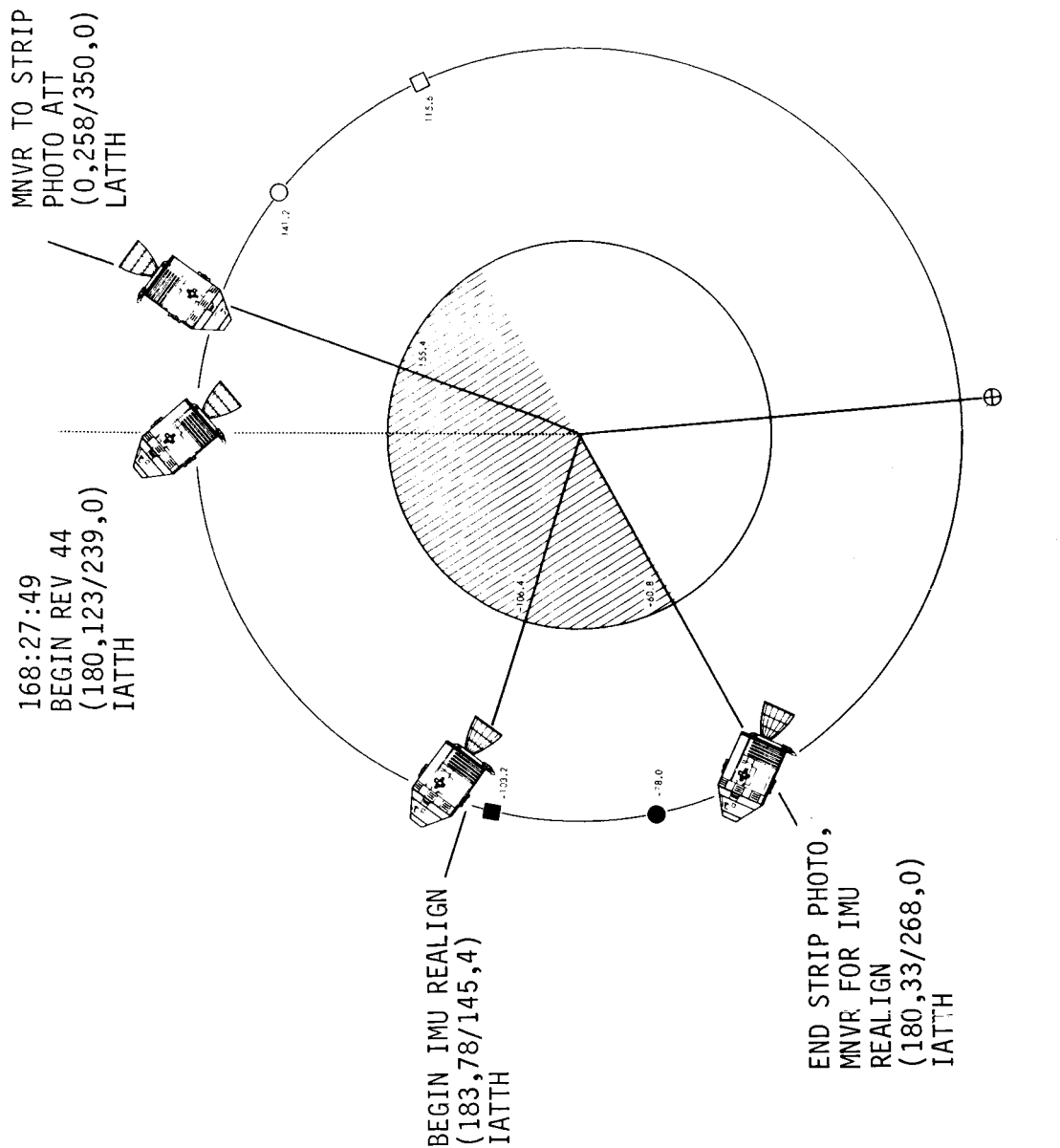


Figure 55. Forty-fourth Revolution Major Events and Attitudes

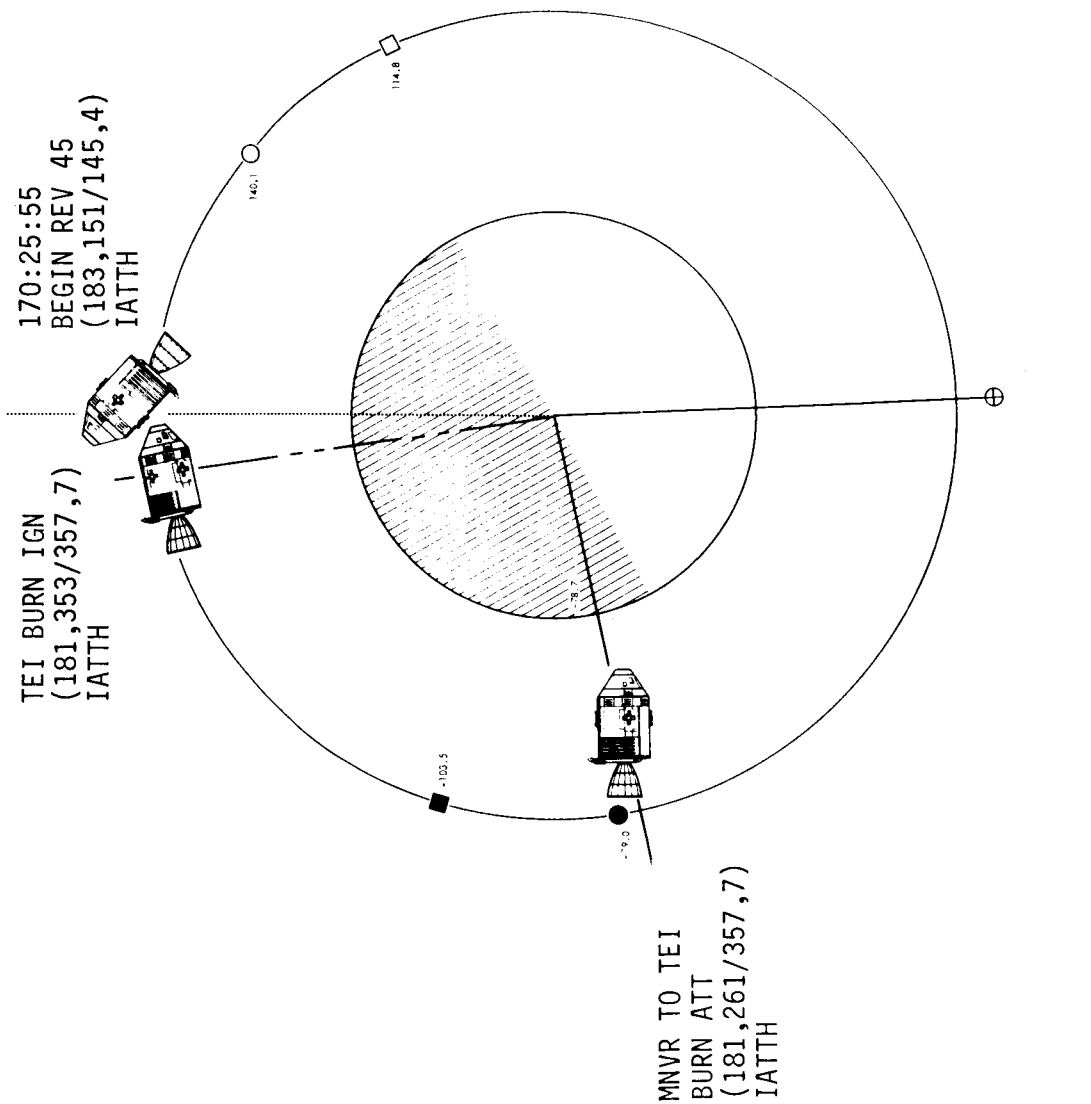


Figure 56. Forty-fifth Revolution to TEI

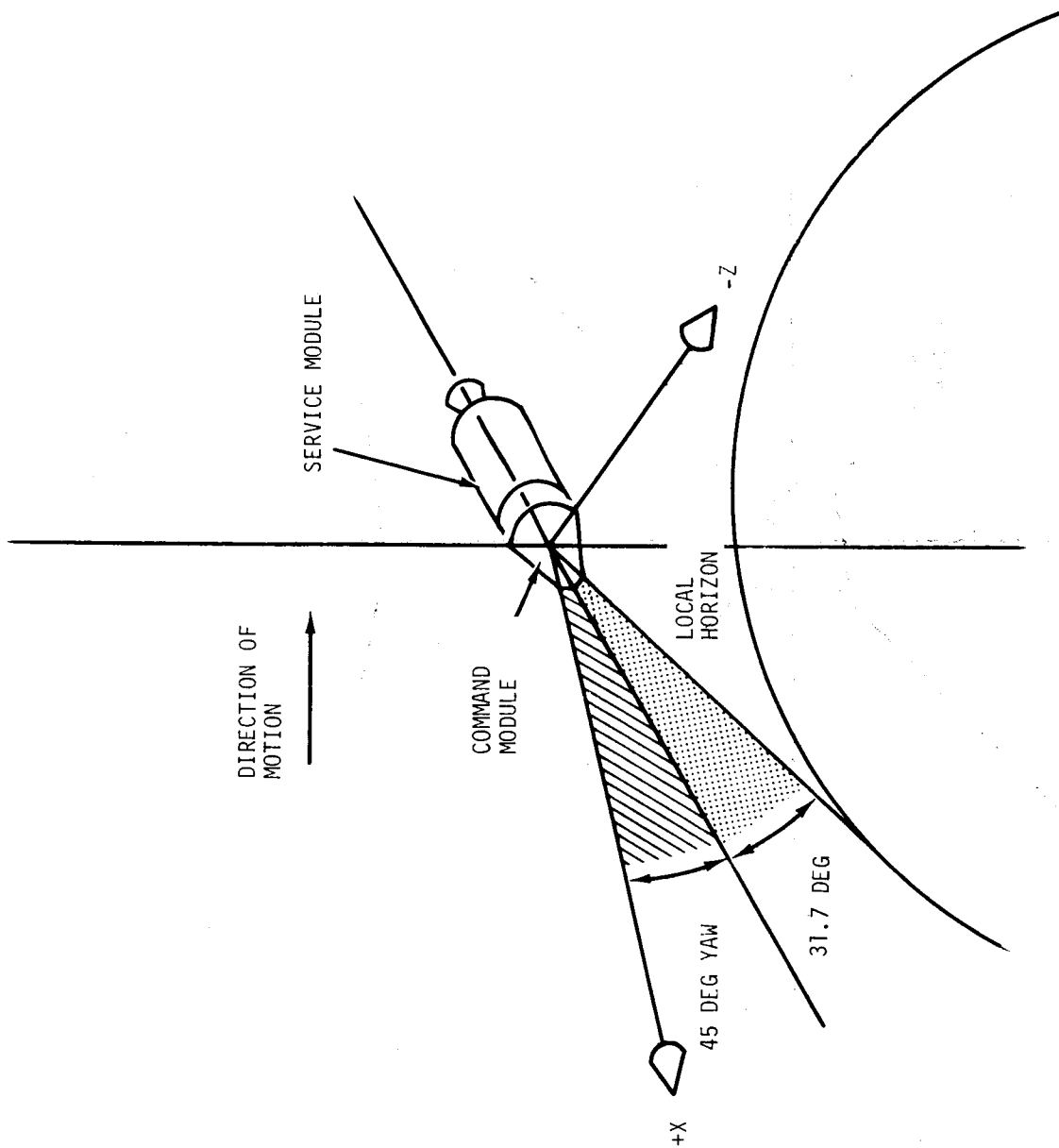


Figure 57. CM/SM Separation Attitude

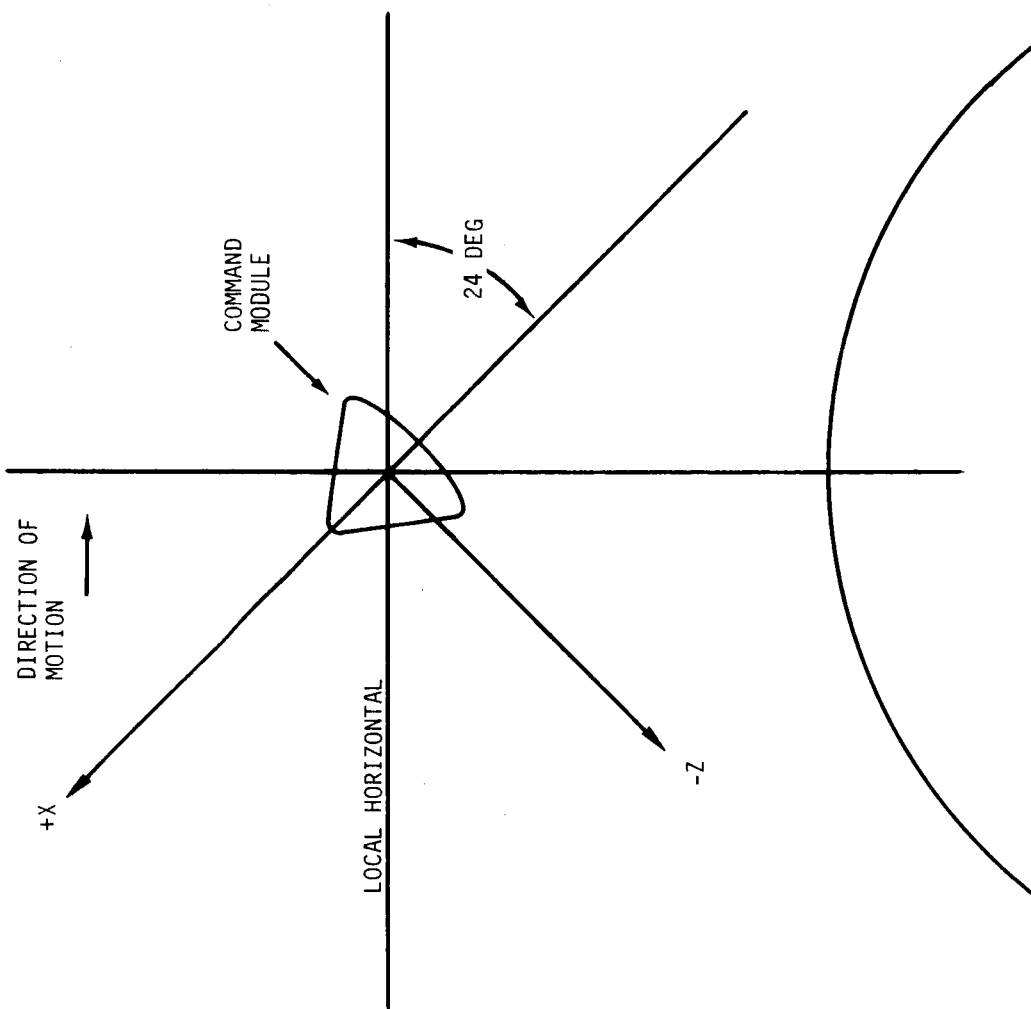


Figure 58. CM Entry Attitude

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